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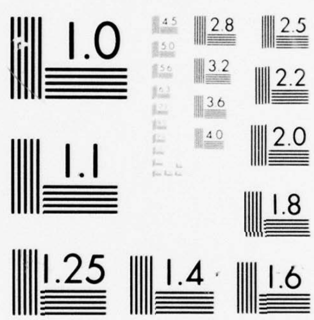
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FINAL REPORT
for
ONR CONTRACT N00014-76-C-0900

EXTENSIONS OF STOCHASTIC NETWORK THEORY TO FACILITATE THE DEVELOPMENT OF MOE'S FOR COMMUNICATION SYSTEMS

by:

Gary E. Whitehouse
John J. Fagan

Department of Industrial Engineering
Lehigh University #19
Bethlehem, PA 18015

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This is the final report for a research contract dealing with the use of Stochastic Network Theory to develop MOE'S for communication systems. GERTS, QGERTS, and GASP IV are used to model Message-switched, Packet-switched, and Circuit-switched communication systems. Areas of future study are presented.

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Introduction

Recent advances in computer-communications technology have given rise to the development of large, complex data communication networks. The high cost of developing and operating these networks have prompted researchers to search for appropriate measures of network performance. Techniques must be made available to analyze network design alternatives in terms of these performance measures. Researchers, however, have found it particularly difficult to develop analytical techniques that will effectively account for all of the complexities inherent in modern computer-communication networks. Consequently, many analysts have turned to simulation as an laternative. This report shows how certain simulation techniques can be used to estimate performance measures for various types of communication networks.

Types of Communication Networks

Communication networks may be conveniently classified into three types as follows:

1) Circuit-Switched
2) Message-Switched
3) Packet-Switched

In circuit-switching, a "call" is set up between subscribers and message transmission takes place in a conversational mode. To set up the call, a path of connecting transmission lines must be established between source and destination. When one subscriber wishes to converse with another subscriber, a signal is transmitted through the network, seizing available channels in an attempt to reach the destination. If no path is available, a busy signal is returned to the caller who must then wait until the necessary channels are free. When a path has been established, message transmission takes place over all of the channels in the path in both directions simultaneously. The path remains allocated to the two subscribers until the caller releases the path or until the call is preempted by a subscriber of higher priority.

At the present time, circuit-switching is the most effective means of accommodating voice transmission, but it can also be used for transmission of data. A good example of a circuit-switched network is the public telephone system. Another is the AUTOVON network used by the Department of Defense for voice transmission.

In message-switching, transmission of data takes place in what is commonly known as a store-and-forward procedure. Unlike circuit-switching, only one channel is

used at a time for any given message transmission. The message first proceeds from its source to some other node in the network according to a predetermined routing algorithm. When the message arrives at this new node, it is either forwarded to the next node in its path or, if no channels are available, it is placed in a queue of messages awaiting transmission. The message proceeds through the network in this manner until it arrives at its destination. This way, a message only needs to occupy one channel at a time rather than an entire path from source to destination, thereby freeing channels for transmission of additional message. The AUTODIN network of the Department of Defense is a good example of a message-switched communication network. Many large corporations also use message-switched networks to satisfy their data transmission needs.

Packet-switching is very similar to message-switching in that it relies on a store-and-forward technique for transmission of messages. The difference, however, is that the messages are broken down at the source into small packets of a fixed size. The individual packets are then transmitted through the network in a manner similar to messages in a message-switched system. When all of the packets have arrived at the specified

destination, they are reassembled and the complete message is transmitted to the receiving subscriber. One of the main advantages of packet-switching is that many packets of the same message may be in tramission simultaneously. As a result, the transmission delay may be considerably less than with message-switching. This is known as the "pipelining" effect.[1] In some instances, transmission delays in a packet-switched environment have been found to be so low that the subscribers can exchange information in a manner similar to circuit-switched communication. The experimental ARPANET is an example of a packet-switched communication network.

Because of the technological and functional differences among the three types of communication networks, different measures are required to evaluate the performance of each type. A discussion of some of the relevant performance measures appropriate for each type of network is included in the following section.

Performance Measures for Communication Networks

Podell (15) has formulated a Measure of Effectiveness (MOE) to characterize the responsiveness of a digital system to any subscriber in a circuit-switched communication network. It is the probability that one of a

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[1] Kleinrock, L., Queueing Systems, Volume II: Computer Applications, John Wiley and Sons, 1976, p. 294.

number of pre-specified subscriber-to-subscriber routes will:

1. be available (not failed in a long-term sense at the instant of demand)
2. not be blocked (by subscribers of equal or higher precedence fully occupying any portion of all of the pre-specified routes)
3. not fail in a long-term sense (over the subscriber's call interval)
4. not fail in a short-term sense (by providing an acceptably low probability of bit error over the call interval
5. not be preempted (over the call interval by a subscriber of higher precedence)

The above joint probability statement is expressed as a sum of mutually exclusive terms, each term corresponding to one of the pre-specified routes through the network.

Podell and others created computer programs to determine the MOE in question in their development of ALAMO (6) and EVALMO (7). These computerized packages have been successfully used by the Defense Communications Agency to evaluate some of their existing and proposed communication systems. There is, however, one major deficiency in these packages and that is that the question of blocking and preemption were assumed to be negligible in these models. Fischer and Knepley (5) describe an algorithm

and a program which can be used to estimate the blocking probabilities by way of an interative procedure, given: the number of trunks in each trunk group of the network; the nodal originating-destination traffic requirements matrix in erlangs and the routing doctrine of the network. However, the work of Fischer and Knepley has not been integrated in the ALAMO and EVALMO packages. Simulation has been suggested as an alternate way of incorporating these particular results.

The store and forward communication networks require a different type of MOE than the one described above for circuit-switched networks. A message-switched or packet-switched network can be designed so that virtually all messages will be completed. This is accomplished by allocating sufficient storage space for the queueing of message at the various nodes in the network. Message queueing, however, can create a problem. If the system becomes overly congested, queues will become very large and the time to successfully transmit a message will increase accordingly. Message transmission time should therefore be a major component of a good measure of effectiveness for store-and-forward communication networks.

In many store-and-forward networks, message storage areas are large enough to insure that no messages will be lost as a result of balking from the message queues. In some instances, however, networks are designed in such a

way that a certain percentage of messages can be expected to balk from the queues during peak operation. This probability of balking should also be included in a measure of effectiveness for store-and-forward networks.

Podell's measure of effectiveness for circuit-switched networks can be used to accommodate message-switched or packet-switched networks if the following revisions are made:

1. The probability of a line being blocked is replaced by the probability of a message being lost as a result of balking from the message queue.
2. Message transmission time is included in the MOE. This can be accomplished by determining the probability that a message will be transmitted within a specified time. Different times might be specified for different precedence levels of messages.

The second and third chapters of this report are devoted to the use of a network simulation language known as QGERT to model message-switched and packet-switched communication networks respectively. The fourth chapter presents a GASP-IV program that can be used to model circuit-switched networks. The purpose of the modelling is to show how these techniques can be used to devise estimates of the performance measures described above. The following two sections contain a brief discussion of the background of QGERT and the symbols and terminology

required to understand the way in which it operates.

Background of QGERT

QGERT is the most recent in a series of programs developed to analyze GERT-type stochastic networks.

GERT was the result of research which effectively extended the work in PERT and CPM. Eisner and Elmagrahby suggested and experimented with additional node and arc logic which would allow for general precedence relationships and probabilistic structure in the network (2,3). Pritsker, Happ and Whitehouse (16,18,20) developed this idea further and defined the stochastic network or GERT network. Stochastic networks are characterized by:

1. Directed arcs representing activities or processes,
2. Each arc is assigned a probability of occurrence and other parameters which describe the distribution of time to traverse the network,
3. Logical nodes which denote the precedence relationship between the incident and emanating arcs of the node, and
4. The realization of the network is a set of arcs or nodes which define the path through the network for one experiment.

Initial work revolved around the analytical solution of GERT networks but after a time the networks became

more complicated and simulation approaches were used. There have been a number of computer packages which have been used effectively in the modelling of GERT type networks. These include:

1. GERTS IIIQ - This special version of GERTS analysis allows for the formulation of problems including Q-nodes. The queueing nodes allow for the modelling of systems which have store and forward features and seem to be effective for modelling some of the more advanced communication systems.
2. GERTS IIIQR - Hogg et al. (8,9,12) have developed a version of GERTS which combines the features of GERTS IIIQ and another model GERTS IIIR, which allows for the modelling of resource allocation considerations into the GERT model. Hogg et al. present a number of examples of their model which seem to be similar to the communication networks approach.
3. QGERT - This was developed by Pritsker (19) as an extended GERTS IIIQ. It accommodates much more advanced queueing logic than was previously available, making it very attractive for modelling fairly complex store-and-forward communication networks. Pritsker is also working on a new ver-

sion of QGERT which was not yet available at the time of this writing.

QGERT: Symbols and Terminology

QGERT is a network modelling technique and a high-level simulation language. The use of QGERT consists of the following two steps:

1. A network model of the system being studied is constructed using the various QGERT symbols.
2. Statistical quantities are derived from the model by using a "canned" computer program called Q-GERTS.

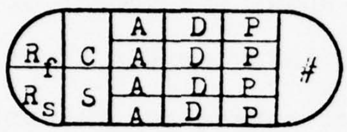
A detailed description of the QGERT modelling technique and the Q-GERTS simulation program can be found in the Q-GERTS User's Manual (19).

In general, a QGERT network consists of a series of nodes and branches. Special symbols are used to model the flow of transactions through the network. The flow of transactions involves: the releasing of nodes representing milestones or events; the performance of activities represented by branches of the network; the storing of transactions at Q-nodes awaiting processing by service activities; the branching of transactions through the network based on past and present conditions within the network; and the collection of statistical information concerning the transactions and the release times of nodes.

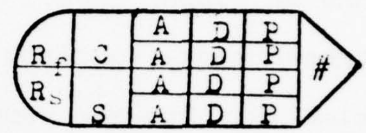
Some of the important QGERT symbols are shown in Figures 1 through 3. Most of the nodes in a QGERT network are regular nodes such as the ones shown in Figure 1. A regular node consists of an input side, a middle section and an output side. The input side shows the number of transactions required to release the node for the first time (R_f) and the number required for subsequent releases (R_s). The middle section is optional. It indicates the criterion for selecting attribute sets from incoming transactions (C); the type of statistics to be collected at the node (S); and the assignment of attributes to transactions passing through the node. Attribute assignment requires the specification of three values: an attribute number (A); one of the 15 distribution types provided in QGERT (D); and a parameter set number (P) indicating the parameters that are to be used in the selection of a value from the distribution specified. Multiple attribute assignments are permitted at a node. Each of the nodes in Figure 1 provides for four different attribute assignments. The output side of a regular node indicates the node number and the type of branching which is to occur from the node. The type of branching is indicated by the shape of the output side of the node. Figure 1(a) shows the symbol for deterministic branching. This means that all activities emanating from this node will be initiated. Probabilistic branching is indicated by Figure 1(b). Only

QGERT Symbols: Regular Nodes

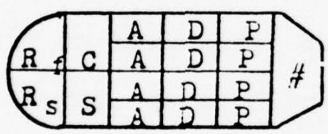
FIGURE 1.



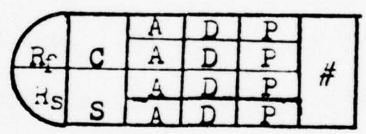
(a) Deterministic



(b) Probabilistic



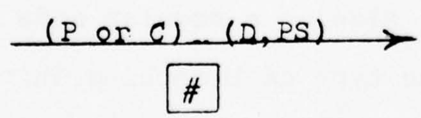
(c) Conditional-Take-First



(d) Conditional-Take-All

QGERT Symbols: Activities

FIGURE 2.



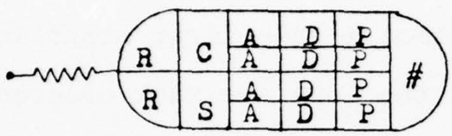
one activity emanating from this node will be selected. The selection is on a random basis according to the probabilities specified on the activities. The symbols for conditional branching are shown in Figures 1(c) and 1(d). QGERT provides 14 condition codes which can be associated with an activity. With conditional-take-first branching, the activities emanating from the node are rank ordered. The conditions associated with the activities are tested in order. When one of the conditions is satisfied, that activity is initiated. For the case of conditional-take-all branching, the conditions for all activities emanating from the node are tested and each activity is initiated if its condition is satisfied.

The branches or activities in a QGERT network are represented in Figure 2. Each activity has associated with it a probability (P) if it emanates from a node with probabilistic branching, or a condition code (C) if it emanates from a node with conditional branching. The time to complete the activity can also be specified. The time can either be constant or it can be a value from a distribution (D) with parameter set (PS). An optional activity number may also be specified. If no time is specified, the activity duration will be zero time units.

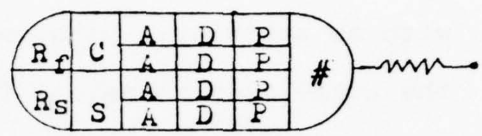
In addition to the regular nodes in a QGERT network, there are a few special-purpose nodes. These are shown in Figure 3. Figure 3(a) represents a source node.

QGERT Symbols: Special-Purpose Nodes

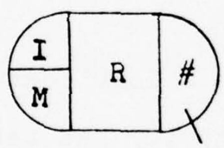
FIGURE 3.



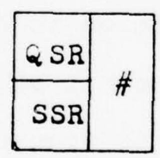
(a) Source Node



(b) Sink Node



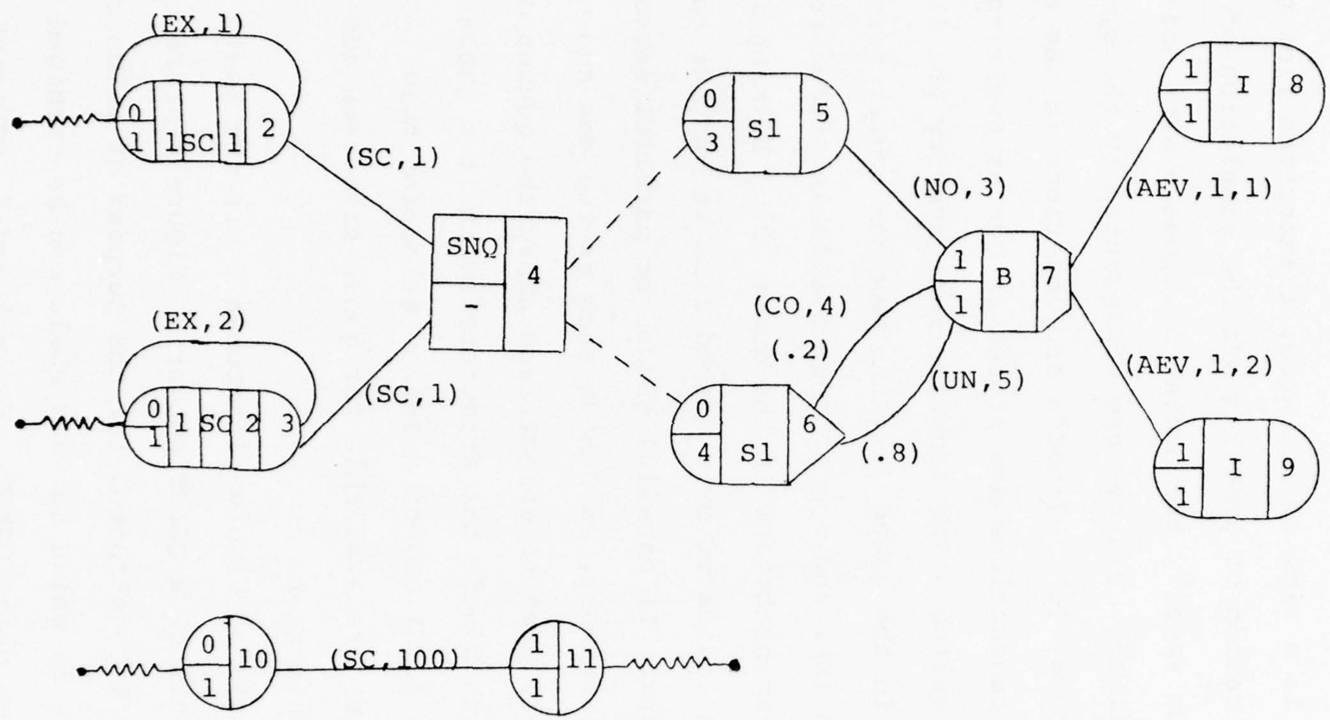
(c) Queue Node



(d) Selector Node

These are the nodes at which transactions are created. Figure 3(b) is a sink node. Here, transaction flow terminates. One method of shutting off the simulation of the network is to specify the number of times a sink node must be realized. Q-nodes are represented by the symbol shown in Figure 3(c). Q-nodes are locations in the network where transactions are stored in queues awaiting further processing. The modeller must specify the initial number in the queue (I), the maximum number permitted in the queue (M), and one of four available procedures for ranking transactions in the queue (R). Balking from the queue is indicated by a dashed line to another node in the network. If parallel queues or parallel servers exist in the network, an S-node such as the one shown in Figure 3(d) is used to select from among the queues or servers. Each S-node has associated with it a queue selection rule (QSR) and/or a server selection rule (SSR). Fourteen rules are available for queue selection and eight for server selection.

The symbols of Figures 1 through 3 are the basic building blocks of a QGERT network. Figure 4 presents a sample network constructed for the purpose of illustrating the ways in which these symbols can be combined to model a system using QGERT. Nodes 2 and 3 represent source nodes. A constant value of 1 is assigned to attribute 1 in node 2, and a constant value of 2 is assigned



A Sample QGERT Model

FIGURE 4.

to attribute 1 in node 3. The branches looping back on nodes 2 and 3 represent the time between arrivals of transactions. The interarrival times are exponentially distributed with parameter sets 1 and 2. The activities from nodes 2 to 4 and 3 to 4 each have a constant duration of 1 time unit. Node 4 is an S-node which sends transactions to one of the parallel queues represented by Q-nodes 5 and 6. The queue selection rule is SNQ. This implies that the S-node will select the queue which currently contains the smallest number of transactions. Q-note 5 allows a maximum of 3 transactions and Q-node 6 allows a maximum of 4. The ranking procedure in both queues is S1, meaning that transactions with the smaller values of attribute 1 will be ranked ahead of those with larger values of attribute 1. The duration of the service activity from node 5 to node 7 is normally distributed with parameter set 3. Q-node 6 has probabilistic branching. The network model indicates that 20% of the transactions will be serviced in a constant time with parameter set 4 and 80% of the transactions will be serviced according to a uniform distribution with parameter set 5. At node 7, statistics are collected on the time between successive realizations of the node. Branching from node 7 is conditional-take-first. Transactions with attribute 1 equal to 1 will be sent to node 8 and transactions with attribute 1 equal to 2 will be sent to node

9. Statistics are collected at nodes 8 and 9, showing the interval of time elapsed since the transaction was last marked. Transactions are automatically marked at source nodes. Since no other marking was indicated in the network, the statistics collected for nodes 8 and 9 will represent the time elapsed between the departure of a transaction from a source node until its arrival at nodes 8 and 9 respectively. Nodes 10 and 11 form a disjoint part of the network sometimes referred to as a "simulation clock." Node 10 is a source node and node 11 is a sink node. The activity between nodes 10 and 11 has a duration of 100 time units. When 100 time units have elapsed, sink node 11 will be realized and the simulation will be terminated.

The Q-GERTS Computer Program

After a system has been modelled using the symbols described in the previous section, the Q-GERTS computer program is used to perform the desired network analysis. Q-GERTS is written in FORTRAN-IV and uses simulation to analyze QGERT networks. The Transition from the QGERT model to the Q-GERTS input is very simple. One data card is required for each node, activity, parameter set, and attribute assignment. An additional card is required to provide some general information about the network. The input is free-form, permitting data to be entered

without card columnrestrictions. Each card contains a three-letter identification to specify the symbol represented by the card and additional parameters to describe the symbol. All values on the card are separated by commas.

The output from the Q-GERTS program includes the following:

1. An echo check of the input.
2. A listing of the input cards.
3. Results of the first simulation of the network (optional).
4. A summary report for the total number of simulations performed. In addition to the statistics called for by the modeller, Q-GERTS provides statistics on: average number in each of the Q-nodes, average server utilization, and average number of transactions balking per unit time from each of the queues.
5. Histograms for each of the statistics collected (tabular or plotted).

The sample QGERT model described in the previous section was analyzed with the Q-GERTS program. The results for five simulations of the network can be found in Appendix A.

MODELLING MESSAGE-SWITCHED COMMUNICATION NETWORKS WITH QGERT

A brief description of the concepts involved in message-switching was included in the introduction. Basically, messages are transmitted from node to node in the communication network in a store-and-forward manner. If all possible communication channels are busy, the message waits in a queue until one of the channels becomes available. This idea of storing-and-forwarding is what makes message-switched networks good candidates for QGERT analysis.

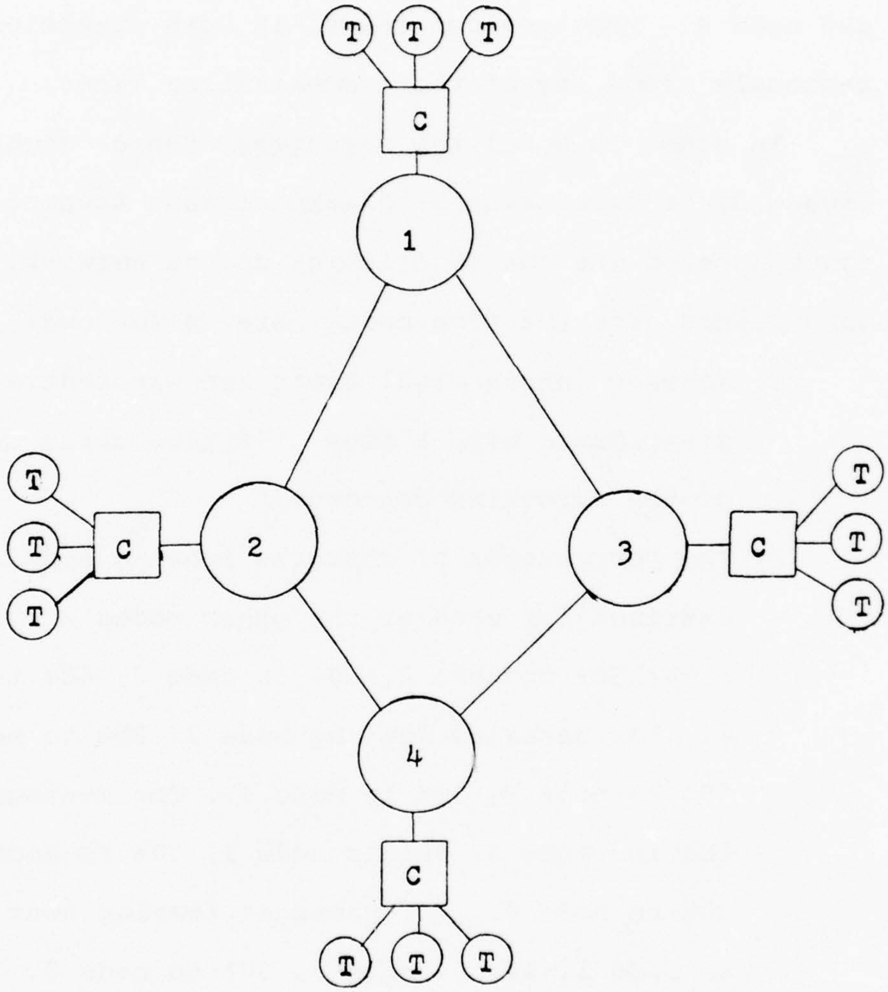
A Hypothetical Network

In order to demonstrate the use of QGERT to model message-switched communication networks, it was decided to use a simple hypothetical four-node communication network. If the concepts in modelling simple networks are understood, they can be easily extended to the modelling of large, fairly complex networks. The network selected for analysis is the one shown in Figure 5.

The nodes in the network of Figure 5 are numbered 1 through 4. The nodes actually represent switching centers that operate by means of message-switching. Each switching center has associated with it a computer (C)

Four-Node Communication Network

FIGURE 5.



and a system of terminals (T). A message originating at any one of the centers can be transmitted to any of the other centers. The network is fully connected except for the fact that there is no direct link between node 1 and node 4. Messages can travel in both directions simultaneously along any of the communication lines.

In order to model the message-switched network of Figure 5, it is necessary to make certain assumptions about some of the characteristics of the network. These assumptions, for the time being, are as follows:

1. Message interarrival times are exponentially distributed with a mean of 2 time units at each of the switching centers.
2. The percentages of messages leaving node 1 and destined for each of the other nodes are as follows: 30% to node 2, 30% to node 3, 40% to node 4. For messages leaving node 2: 30% to node 1, 40% to node 3, 30% to node 4. For messages leaving node 3: 40% to node 1, 30% to node 2, 30% to node 4. For messages leaving node 4: 30% to node 1, 40% to node 2, 30% to node 3.
3. There are 3 priority classes of messages. The breakdown is as follows: 10% are priority 1 (high priority); 30% priority 2; 60% priority 3. This distribution holds for all combinations of source and destination.

4. Message length (in terms of transmission time) is exponentially distributed with a mean of 10 time units for all types of messages.
5. The times required to transmit a single bit of information along each of the communication links (a function of the length of the link) are as follows: 2.5 time units between nodes 1 and 2; 3.0 time units between nodes 1 and 3; 2.0 between 2 and 3; 1.0 between 2 and 4; 1.5 between 3 and 4.
6. Queues are large enough so that no messages will be lost as a result of balking. The messages in the queues are ranked according to priority, but high priority messages do not preempt lower priority messages.
7. Messages going from node 1 to node 4 are initially routed to node 3 and messages going from node 4 to node 1 are initially routed to node 2.
8. Each of the communication lines in the network contains four channels for message transmission.

With these characteristics in mind, a QGERT model of the four-node message-switched communication network of Figure 5 was developed. The following section explains the model in detail.

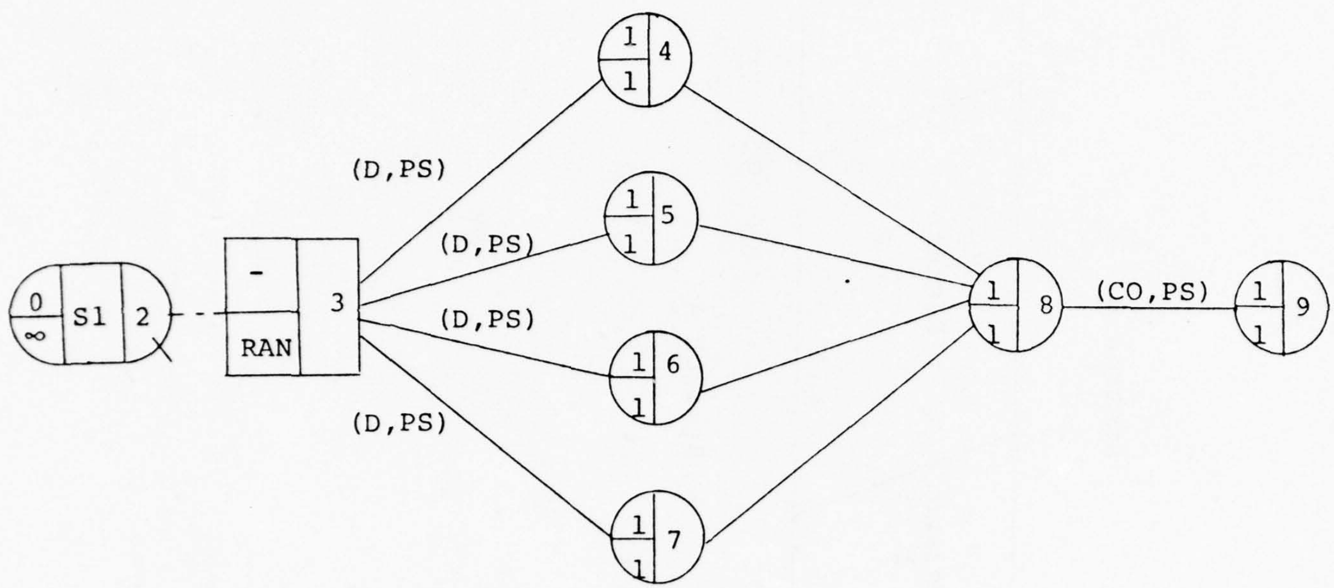
Development of the QGERT Model

The key to modelling a store-and-forward communication network is to think of a communication line as a

series of parallel servers. The parallel servers are the various communication channels in the line. The transactions that they serve are the messages that are being transmitted over the channels. Figure 6 depicts a sample communication line with 4 channels as it would be modelled using QGERT.

Node number 2 is a Q-node. It represents the storage area for messages awaiting transmission. Node 3 is an S-node. It selects from among the four communication channels in the line. The server selection procedure is random (RAN). This implies that if more than one channel is available for the transmission of a message, the available channels have an equal probability of being selected. The channels are represented by the activities from node 3 to nodes 4,5,6, and 7 respectively. Message transmission time is made up of two components. The first component is variable and is dependent on the message length. It is represented as a value from a distribution D with parameter set PS and is shown on the service activities emanating from node 3. The second component is fixed and is a function of the length of the communication line. It is represented on the activity between nodes 8 and 9 as a constant value with parameter set PS.

The principle of the two components of message transmission time is illustrated in Figure 7. Two messages are being sent from station A to station B.

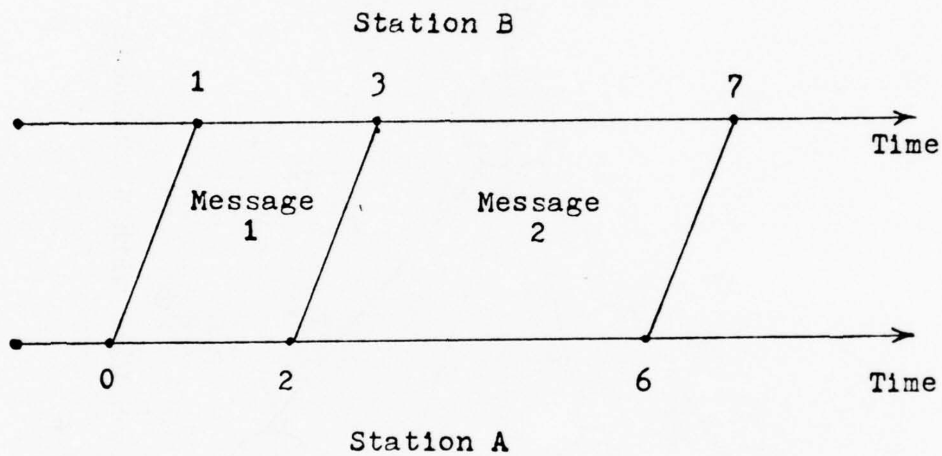


QGERT Model of a Communication Line with 4 Channels

FIGURE 6.

Two Components of Message Transmission Time

FIGURE 7.



Transmission of message 1 at station A begins at time 0 and ends at time 2 for a variable component of 2 time units. The fixed component of transmission time is 1 time unit so that station B begins to receive the message at time 1. Transmission of message 1 is completed when the last bits of information are received by station B at time 3. Total transmission time is 3 time units. Transmission of message 2 begins at time 2 and ends at time 6 for a variable component of 4 time units. Transmission is completed at time 7 for a total transmission time of 5 time units.

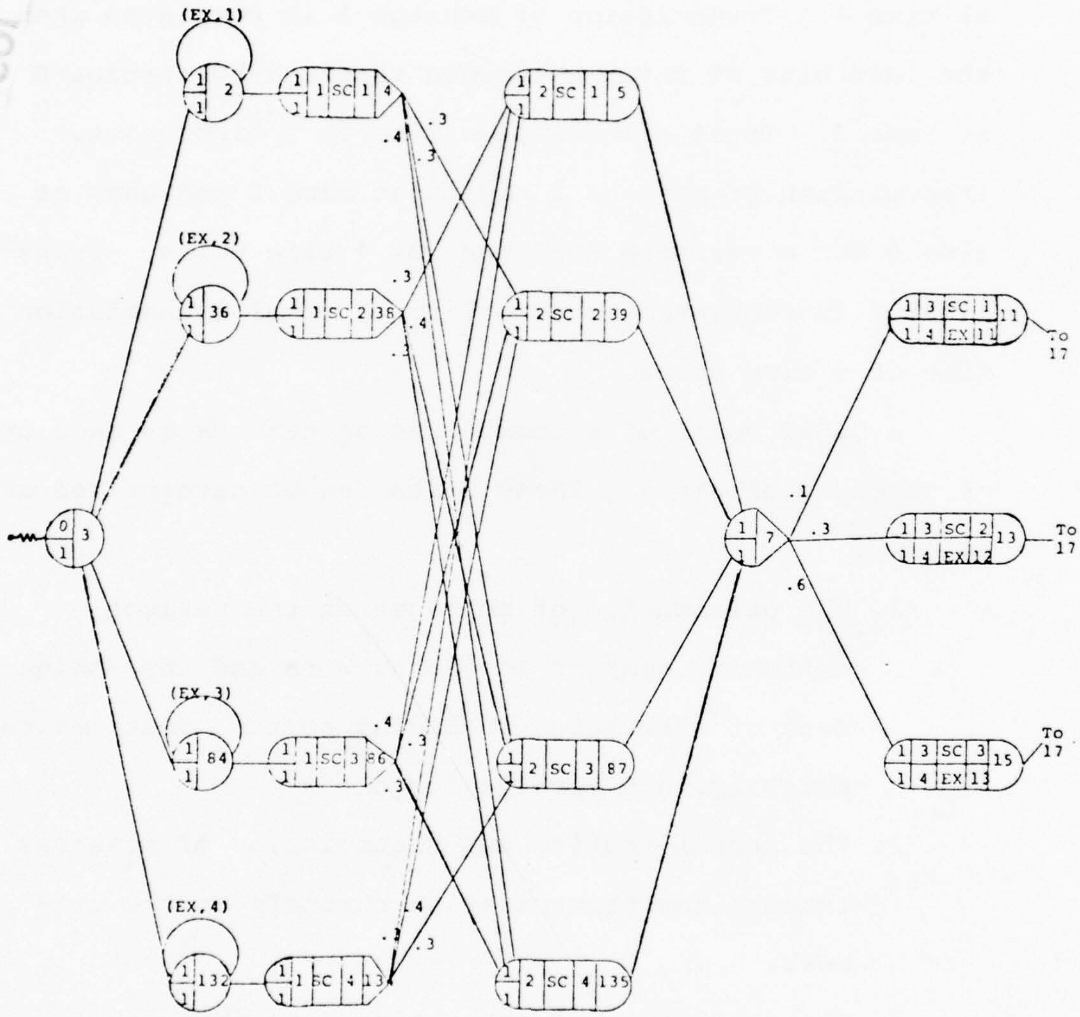
A QGERT model of a communication network is made up of three major parts. These parts can be categorized as follows:

1. The origination of messages at the various switching centers in the network and the assignment of attributes including source, destination, priority, and message length.
2. The actual routing and transmission of messages through the communication channels of the network.
3. The collection of statistics describing the performance of the network.

The entire QGERT model of the four-node message-switched communication network of Figure 5 appears in Figure 8. Parts a, b, and c of Figure 8 correspond to

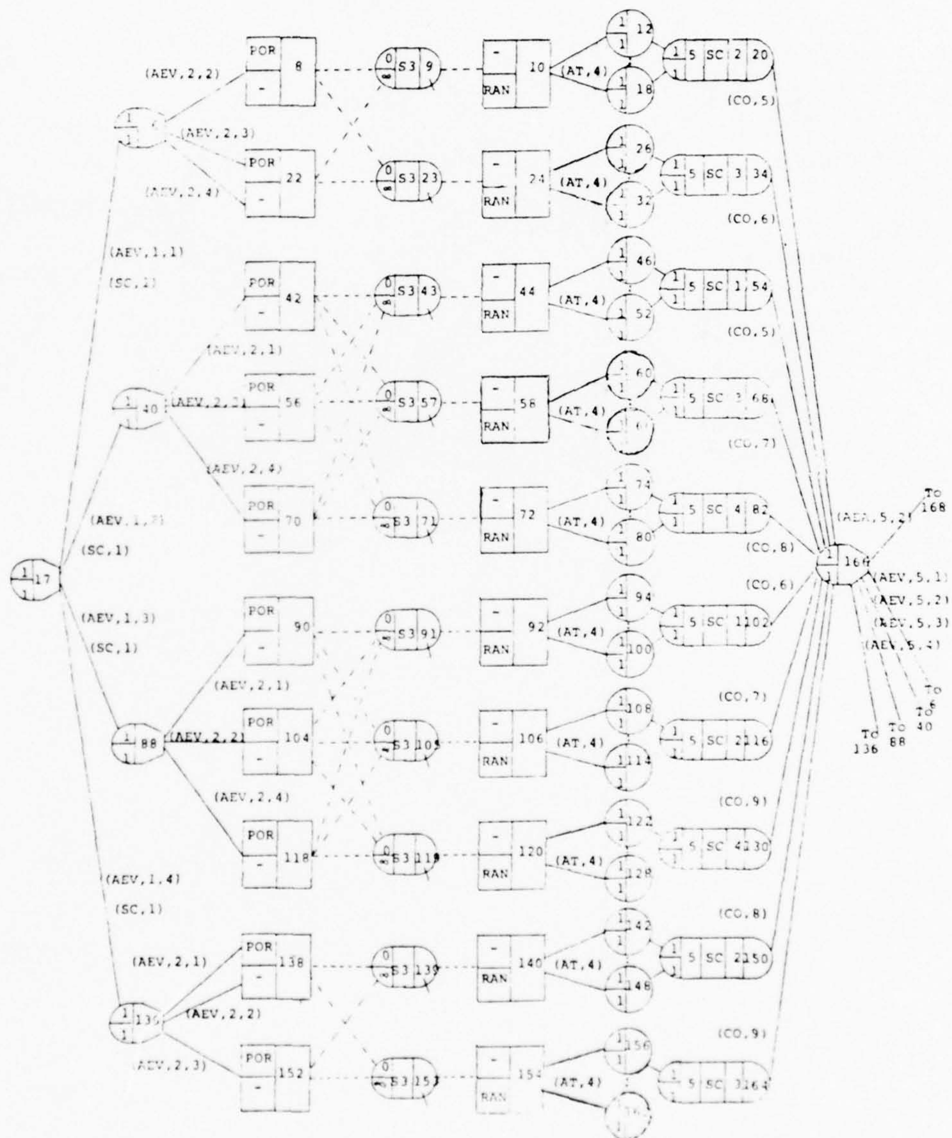
QGERT Model of a Four-Node Message-Switched Communication Network: Message Generation

FIGURE 8(a)



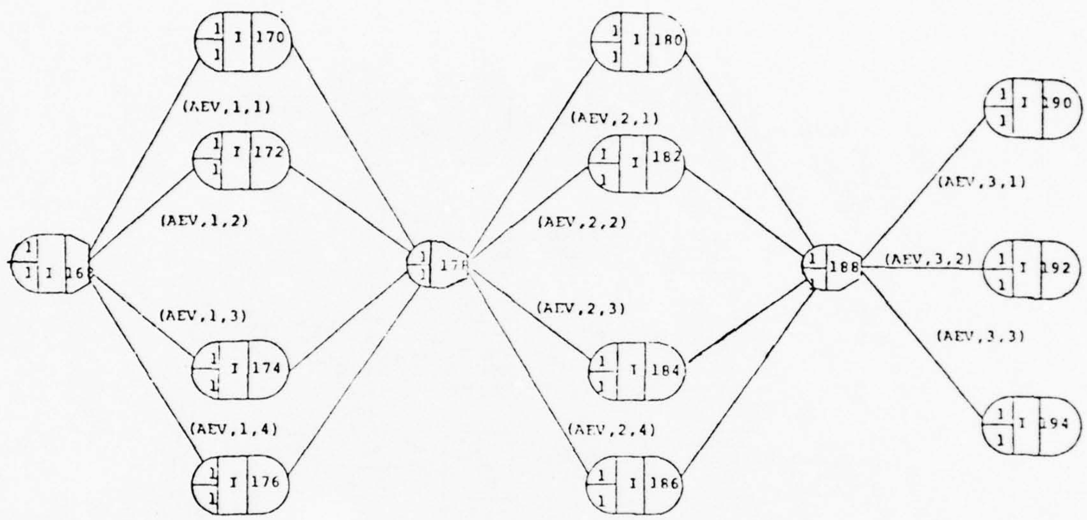
QGERT Model of a Four-Node Message-Switched Communication Network: Routing and Transmission

FIGURE 8(b)



QGERT Model of a Four-Node Message-Switched Communication Network: Statistics Collection

FIGURE 8(c)



the three parts of the model as described above. The remainder of this section is devoted to an explanation of the model.

Nodes 2, 36, 84, and 132 represent the four switching centers in the network where messages originate. The activities looping back on these nodes represent the time between arrivals of messages. Interarrival times are exponentially distributed with a mean of two time units at each of the centers. The distribution of interarrival times can be easily modified by changing the values in parameter sets 1, 2, 3, and 4.

Values of attribute number 1 are assigned at nodes 4, 38, 86, and 134 indicating the origin of a message at stations 1, 2, 3, and 4 respectively. The branching from each of these nodes is probabilistic. The activities emanating from them show the probabilities of messages being sent to each of the other stations in the network (in accordance with the proportions stated in the description of the network in the previous section). The destination of a message is indicated by values assigned to attribute number 2 at nodes 5, 39, 87, and 135. The activities emanating from these nodes feed into node 7. Branching from node 7 is probabilistic also, with 10% of the transactions going to node 11, 30% to node 13, and 60% to node 15.

Values of attribute numbers 3 and 4 are assigned at nodes 11, 13, and 15. Attribute number 3 indicates the message priority level. A constant value of 1 is assigned at node 11, 2 at node 13, and 3 at node 15 indicating messages of high priority, middle priority, and low priority respectively. Attribute number 4 represents the message length in terms of transmission time. Transmission time is exponentially distributed with parameter set 11 for high priority messages, 12 for middle priority messages, and 13 for low priority messages. Initially, all three distributions have a mean of 10 time units (as specified in the network description).

Following the assignment of attributes 3 and 4, the message is sent to node 17 to determine where it should be routed for initial transmission. At this point, no time has elapsed since the origination of the message.

Branching from node 17 is conditional-take-first, based on the value of attribute 1. Messages from source number 1 (ie.: those with attribute 1 equal to 1) are sent to node 6; messages from source 2 are sent to node 40; messages from source 3 are sent to node 88; and messages from source 4 are sent to node 136. The activities emanating from node 17 all have a constant time of 1 associated with them. This is the time required to process the message prior to transmission. Branching from nodes 6, 40, 88, and 136 is also conditional-take-first, this

time based on the value of attribute number 2 (the destination of the message). Messages are routed from these nodes to an appropriate S-node in order to select a communication line for transmission. For example, a message with attribute 1 equal to 2 and attribute 2 equal to 3 will be initially routed to node 40 and then to S-node number 56. At this point, the message will be sent to one of three possible Q-nodes (43, 57, or 71) depending on the queue selection rule specified for the S-node. In this case, the queue selection rule for each of the S-nodes is POR which stands for "preferred order." The preferred order for messages going from source 2 to destination 3 is Q-node 57, followed by Q-node 71, followed by Q-node 43. Q-node 57 represents the queue of messages awaiting transmission over the link between stations 2 and 3; Q-node 71 represents the queue for the link between stations 2 and 4; and Q-node 43 represents the queue for the link between stations 2 and 1. Each of the Q-nodes in Figure 8(b) has an infinite queue length. Therefore, the queues will never be full and all messages going from station 2 to station 3 will be initially routed to Q-node 57. If, however, a limit was placed on the size of the queues and the queue for node 57 became full, a message going from station 2 to station 3 would have to be placed in the queue at node 71 and would initially be transmitted to station 4 before going on to station 3. If the queue

at node 71 was also full, the message would be placed in the queue at node 43 and would be transmitted to station 1 initially.

There are 10 Q-nodes in Figure 8(b). Each of the Q-nodes is followed by an S-node and a set of parallel servers, making up the symbol set for a communication link as was previously described in the explanation of Figure 6. There are 2 such sets of symbols for each of the 5 links in the communication network, representing the transmission of messages in both directions over the link. The ranking procedure for each of the queues is S3, meaning that messages are ranked according to attribute 3 with small values first. Attribute 3 was used to designate the priority class of the message. The activity times for the service activities are shown as (AT,4). This means that the time to complete the activity will be equal to the value stored in attribute 4 for each message. Attribute 4 was used to assign a value representing the variable component of the message transmission time. Each of the communication lines contains 4 channels. Because of limited space, however, Figure 8(b) only shows 2 channels for each of the lines. The other channels are indicated by a series of dots.

After a message has been transmitted over one of the communication lines, a value is assigned to attribute 5 indicating the station to which the message has just been

transmitted. The message is then sent to node 166. The times on the activities leading into node 166 represent the fixed component of message transmission time and correspond to the values given for each of the lines in the description of the network. Branching from node 166 is conditional-take-first. A check is made to see if attribute 5 is equal to attribute 2. If it is, the message has arrived at its destination and is ready to be sent to the statistics collection part of the network. If not, the message is routed back to node 6, 40, 88, or 136 (depending on the value of attribute 5) for further transmission.

When a message arrives at its destination, it is sent from node 166 to node 168 for statistics collection. Node 168 is a statistics node which calls for the collection of "interval" statistics. This is designated by the letter I in the central portion of the node. Statistics associated with node 168 on the Q-GERTS output will indicate the average time spent in the system for all messages. Branching from node 168 is conditional-take-first, based on attribute 1 (the source of the message). Interval statistics for nodes 170, 172, 173, and 174 will indicate the average time in the system for messages originating at stations 1, 2, 3, and 4 respectively. Next, messages are routed according to the value of attribute 2 (destination) to node 180, 182, 184, or 186 where

statistics will be collected indicating average time in the system for messages which have arrived at stations 1, 2, 3, and 4 respectively. Finally, messages are routed from node 188 to node 190, 192, or 194 where interval statistics are collected for the three priority levels of messages. Statistics for high priority messages are collected at 190; middle priority at node 192, and low priority at node 194.

The subnetwork consisting of source node 175 and sink node 173 is the simulation clock. The activity time for the branch connecting the two nodes indicates that the simulation is to be run for 300 time units. In the input to the Q-GERTS program, it will be specified that statistics collection is not to begin until 100 time units have elapsed. This permits the system to reach a steady-state before any statistics are collected. Statistics will therefore be collected over an interval of 200 time units.

Simulation Results

The Q-GERTS program was used to analyze the network described in the previous section. The input to the program consists of one card for each of the nodes, activities, parameter sets, and attribute assignments shown in Figure 8; and a card that contains some general information about the network being modelled. The information contained on this card includes the following:

1. A three letter ID to indicate that the card contains general information (GEN).
2. The name of the analyst.
3. The project number.
4. The date.
5. The number of sink nodes in the network (1).
6. The number of nodes for which statistics are kept (13).
7. The number of sink nodes to realize the network (1).
8. The number of simulations of the network (2).
9. An integer random number seed.
10. The maximum number of attributes associated with each transaction flowing through the network (5).
11. The time from which statistics will be kept (100.0).
12. The type of histogram desired (tabular).

The GEN card must be the first card in the input deck. It is followed by the cards representing the nodes, parameter sets, and attribute assignments. These can be arranged in any order and are followed by cards representing the activities in the network. The last card in the input deck contains the letters "FIN".

The results of 2 simulations of the network shown in Figure 8 are as follows:

1. Average message transmission times

Message Type	Node No.	No. of Time Units
Priority 1	190	12.3361
Priority 2	192	16.0297
Priority 3	194	19.3908
Source 1	170	27.2049
Source 2	172	12.3500
Source 3	174	14.0068
Source 4	176	17.1912
Destination 1	180	17.4733
Destination 2	182	13.2201
Destination 3	184	15.1907
Destination 4	186	25.4596
All Messages	168	17.7135

2. Average number in Message Queues

Communication Link	Node No.	Avg. No. in Queue
1 to 2	9	.0154
1 to 3	23	3.7137
2 to 1	43	.4964
2 to 3	57	.0655
2 to 4	71	.0000
3 to 1	91	.0552
3 to 2	105	.0047
3 to 4	119	2.1353
4 to 2	139	1.7557
4 to 3	153	.0958

3. Average Channel Utilization

Communication Link	Activity No.[2]	Percentage Busy Time
1 to 2	198	.2400
	197	.3546
	196	.3673
	195	.4055
1 to 3	194	.9067
	193	.9168
	192	.8631
	191	.9088
2 to 1	190	.6405
	189	.6398
	188	.6043
	187	.7193
2 to 3	186	.4684
	185	.5523
	184	.4080
	183	.4815
2 to 4	182	.3320
	181	.4038
	180	.2858
	179	.3909
3 to 1	178	.3933
	177	.4717
	176	.4371
	175	.5121

[2]The QGERTS program assigns activity numbers to service activities if none are specified in the program input.

3 to 2	174	.3530
	173	.3457
	172	.4700
	171	.3129
3 to 4	170	.7801
	169	.8230
	168	.8815
	167	.7987
4 to 2	166	.8115
	165	.8177
	164	.8731
	163	.9008
4 to 3	162	.4400
	161	.5247
	160	.4227
	159	.4256

A complete listing of the Q-GERTS input and output (which includes much more information than what is shown above) for this model can be found in Appendix B.

Modification of the Network

One of the interesting features of the QGERT modelling technique is the ease with which a model can be modified. For example, the interarrival time of messages at one of the stations in the communication network can be modified simply by changing the values on one card in the input desk. The same is true for such parameters as: activity times, probabilities of selecting among activities,

maximum queue lengths, attribute values, and queue or server selection rules. There are three major modifications that an analyst might wish to make to the model of the message-switched communication network shown in Figure 8. These are:

1. To limit the size of message queues and permit messages to "balk" from the system.
2. To allow for more generalized message generation.
3. To account for changes in the structure of the communication network.

The remainder of this section discusses the changes that must be made to the QGERT model in Figure 8 in order to implement these modifications.

1) Limiting the size of message queues

The QGERT model discussed in the previous section permitted queues of messages to build up indefinitely. This insured that all messages would eventually be transmitted successfully. In reality, there must be some limit to the number of messages that can be allowed to accumulate in a storage area. If the maximum queue length is small, some of the messages will balk from the queues and will not be completed. In order to incorporate this idea into the QGERT model of a message-switched communication network, the following changes must be made to the model in Figure 8:

a) The maximum number permitted in the queues must be changed from an indefinitely large number to whatever the actual maximum is.

b) For each of the selector nodes, a node number must be specified to show where balkers are to be sent. If all of the queues associated with a particular S-node are full, an arriving message will balk to this specified node.

c) The portion of the network model devoted to statistics collection must be revised to collect statistics on the messages that balk from the queues.

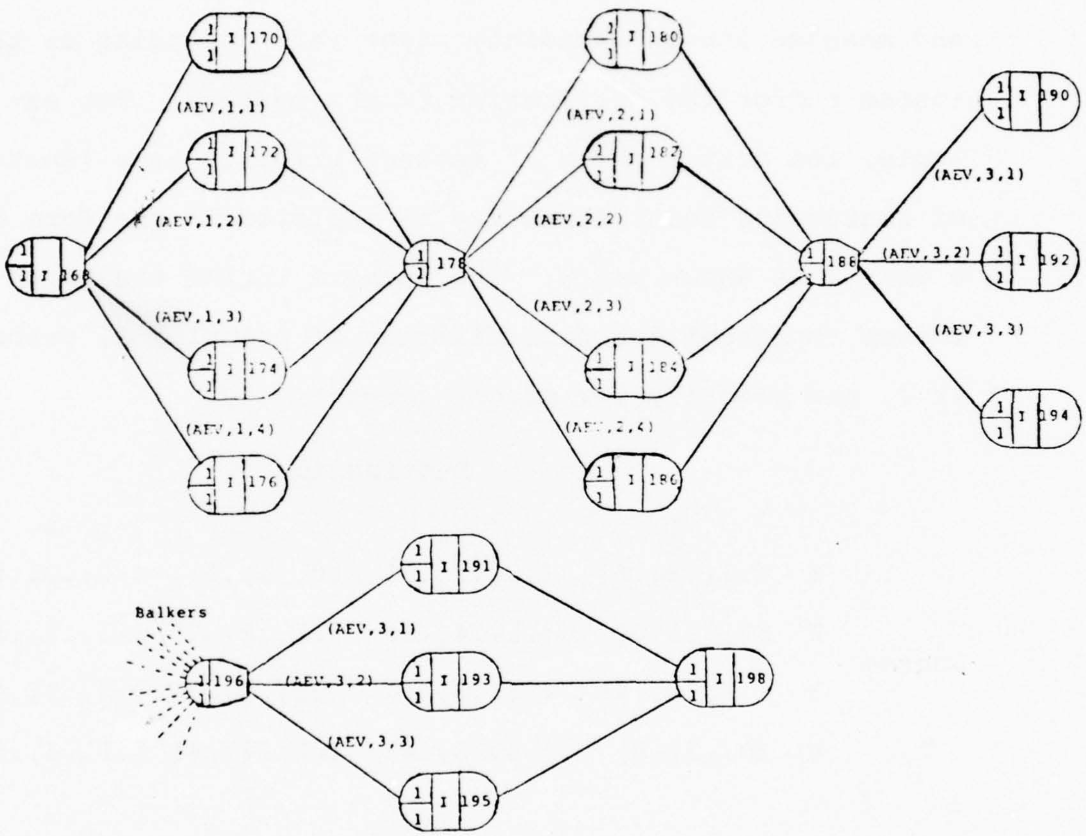
The Q-GERTS program was used to analyze a message-switched network similar to the one modelled in Figure 8 where the queues were limited to a maximum of 5 messages. The revised statistics section of the model is shown in Figure 9. All messages that balk from the queues are sent to node 196. Nodes 191, 193, and 195 specify that statistics are to be collected on messages of priority 1, 2, and 3 respectively that balk from the system. Statistics for all balking messages are collected at node 198. The results for 2 simulations of this modified network can be found in Appendix C.

2) Generalized Message Generation

In the original model of the message-switched communication network, it was assumed that the distribution of

Statistics Collection for a QGERT Model of a Four-Node Message-Switched Communication Network with Balkers

FIGURE 9.



message priorities was the same for all combinations of source and destination; and that the distribution of message lengths was a function of the priority level only. In reality, however, the distributions of priority level and message length certainly might vary depending on the source and/or the destination of the message. For example, the distribution of message priority as a function of source and destination may be depicted in the form of a matrix as shown below. The numbers inside the parentheses represent the probabilities of priority 1, priority 2, and priority 3 messages respectively.

		Destination			
		1	2	3	4
Source	1	(.1,.3,.6)	(.2,.3,.5)	(0,.1,.9)	(.2,.2,.6)
	2	(0,0,1.0)	(.1,.4,.5)	(.1,.2,.7)	(.1,.3,.6)
	3	(.3,.3,.4)	(.1,.3,.6)	(.1,.4,.5)	(.2,.3,.5)
	4	(0,.2,.8)	(.3,.3,.4)	(.2,.4,.4)	(.1,.3,.6)

This generalization of the types of messages originating at the various nodes in the network can be incorporated in the QGERT model. First, however, it is necessary to introduce a feature of QGERT that has not yet been described.

QGERT permits the user to access a FORTRAN function within the framework of the symbols that make up the model. The function is given the name USERF. It is written by

the user and may be accessed by either of the following methods at various locations in the model:

a) To access the function USERF at a node, the user must specify an attribute assignment with the distribution code UF.

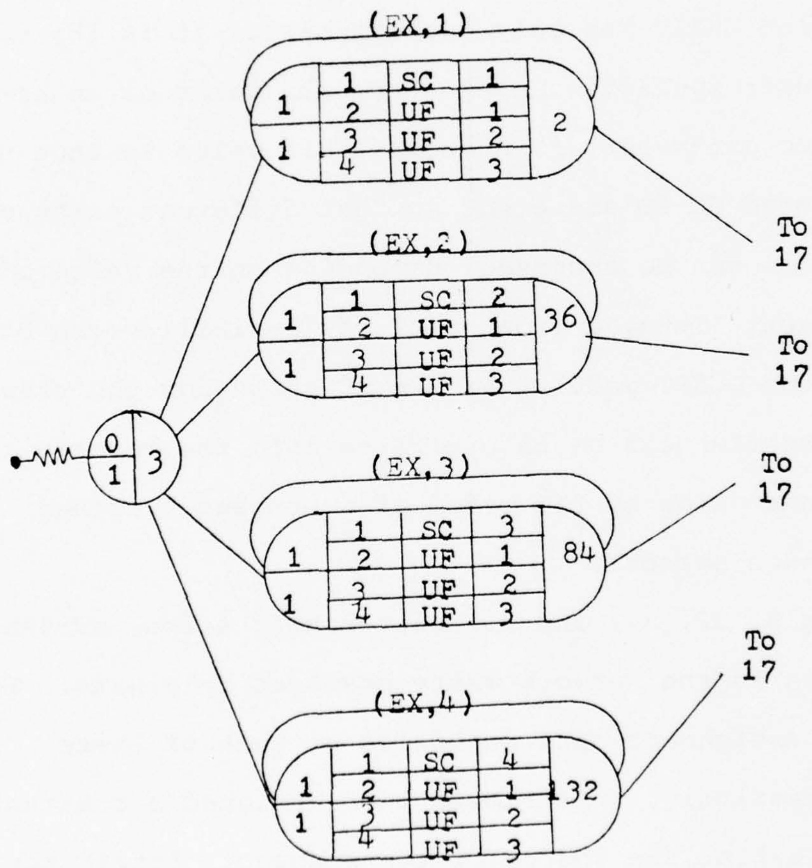
b) To access the function USERF on an activity, the user must specify an activity time with the distribution code UF.

The function USERF has only one argument. It is the value that the user specifies as an attribute value or an activity time parameter set number. This value is then used in a computed GO TO statement so that different parts of the function can be accessed, depending on the value of the argument. Thus, a great deal of flexibility can be added to the QGERT model. Figure 10 shows how the user-written function can be incorporated into the message generation section of the model of a message-switched communication network.

Nodes 2, 36, 84, and 132 represent the four switching centers in the network where messages originate. Four attribute assignments are specified at each of these nodes respectively. Attribute 1 is assigned a constant value indicating the source of the message. Attributes 2, 3, and 4 specify that function USERF is to be used to assign values for destination, priority level, and message length respectively. Not only is the number of nodes

Message Generation for QGERT Model of a Four-Node Message-Switched Communication Network with FORTRAN Function USERF

FIGURE 10.



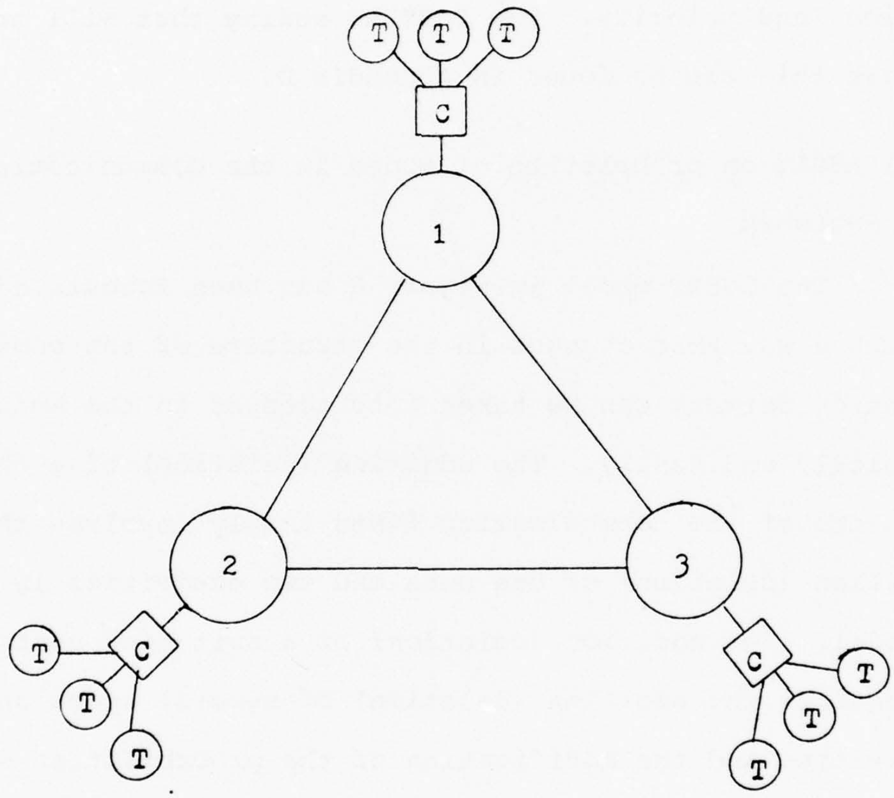
and activities significantly reduced from that of Figure 8, but the origination of messages in the network can be performed in a much more generalized manner. Message priority can be made a function of source and destination; and message length a function of source, destination, and priority. The FORTRAN coding that will accomplish this can be found in Appendix D.

3) Addition or Deletion of Nodes in the Communication Network

The QGERT model in Figure 8 has been formulated in such a way that changes in the structure of the communication network can be taken into account in the model quickly and easily. The addition (deletion) of a channel in one of the communication lines simply involves the addition (deletion) of one node and two activities in the model. The addition (deletion) of a switching center requires the addition (deletion) of several nodes and activities and the modification of the probabilities showing the proportions of messages going from the various sources to each of the destinations. To illustrate, suppose switching center number 4 was deleted from the original message-switched network. This would leave the three-node network of Figure 11. Rather than listing the nodes and activities that must be deleted from the model in Figure 8, a revised model of the new three-node network is presented in Figure 12. In general, the

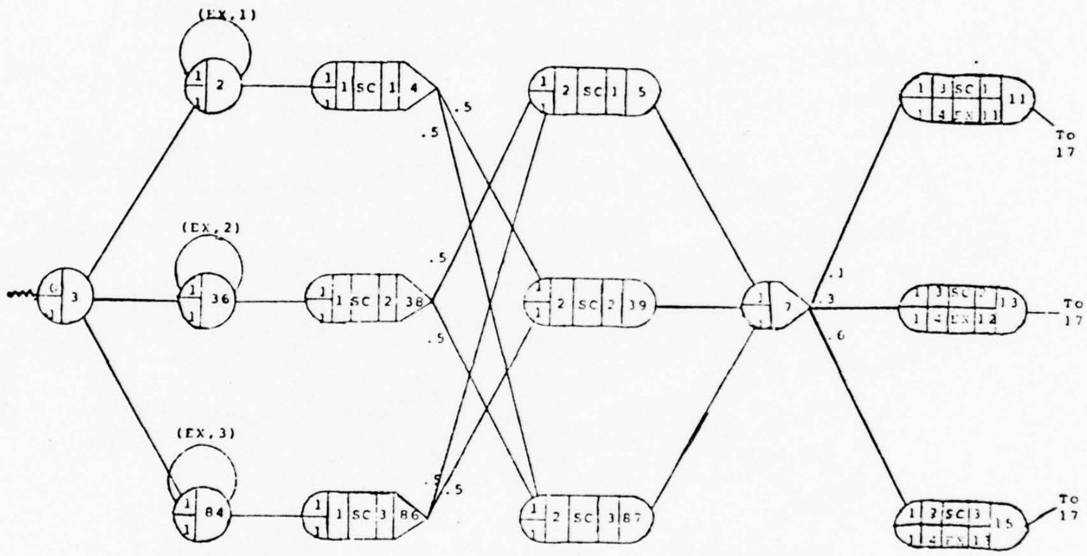
Three-Node Communication Network

FIGURE 11.



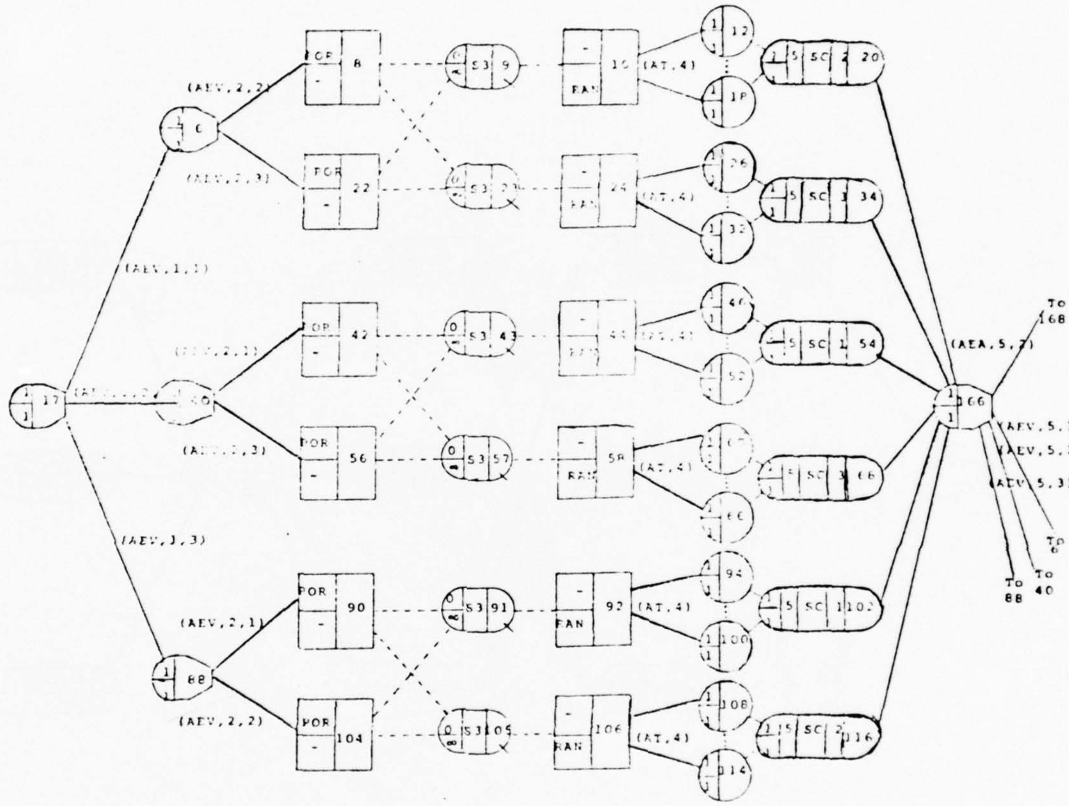
QGERT Model of a Three-Node Message-Switched Communication Network: Message Generation

FIGURE 12(a)



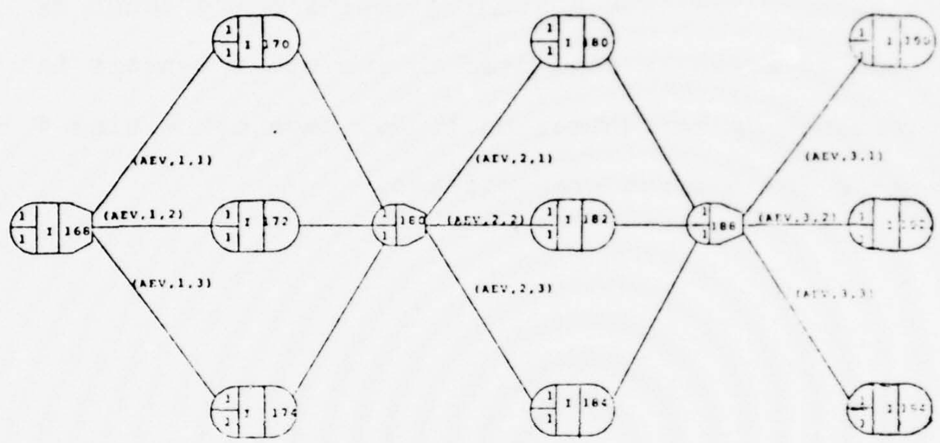
Q-GERT Model of a Three-Node Message-Switched Communication Network: Routing and Transmission

FIGURE 12(b)



QGERT Model of a Three-Node Message-Switched Communication Network: Statistics Collection

FIGURE 12(c)



addition (deletion) of a switching center requires the addition (deletion) of approximately 22 nodes in the model and about twice as many activities (the number of activities depending to a slight extent on the total number of switching centers in the network at the time). This assumes that the switching center being added or deleted is directly connected to two other centers in the network by communication lines, each containing 4 channels for message transmission.

MODELLING PACKET-SWITCHED COMMUNICATION NETWORKS WITH QGERT

Packet-switching, as discussed in the introduction, is very similar to message-switching. It uses the store-and-forward technique for transmission of messages. The basic difference, however, is that messages are divided into small packets at the source and the packets are transmitted through the network independently. It is quite possible that two packets of the same message might take completely different paths to the specified destination. All packets are of a uniform size. Consequently, processing of packets at the switching centers can be performed very quickly. When all of the packets arrive at the specified destination, they are automatically reassembled into the original message.

The QGERT Model

For the sake of simplicity and to set up a basis for comparison, the four-node communication network of Figure 5 was selected to demonstrate the use of QGERT to model packet-switched networks. The switching centers in the network are now assumed to operate on the principle of packet-switching rather than message-switching. Also, it is assumed that the number of packets in a message is poisson distributed with a mean of 5 packets for

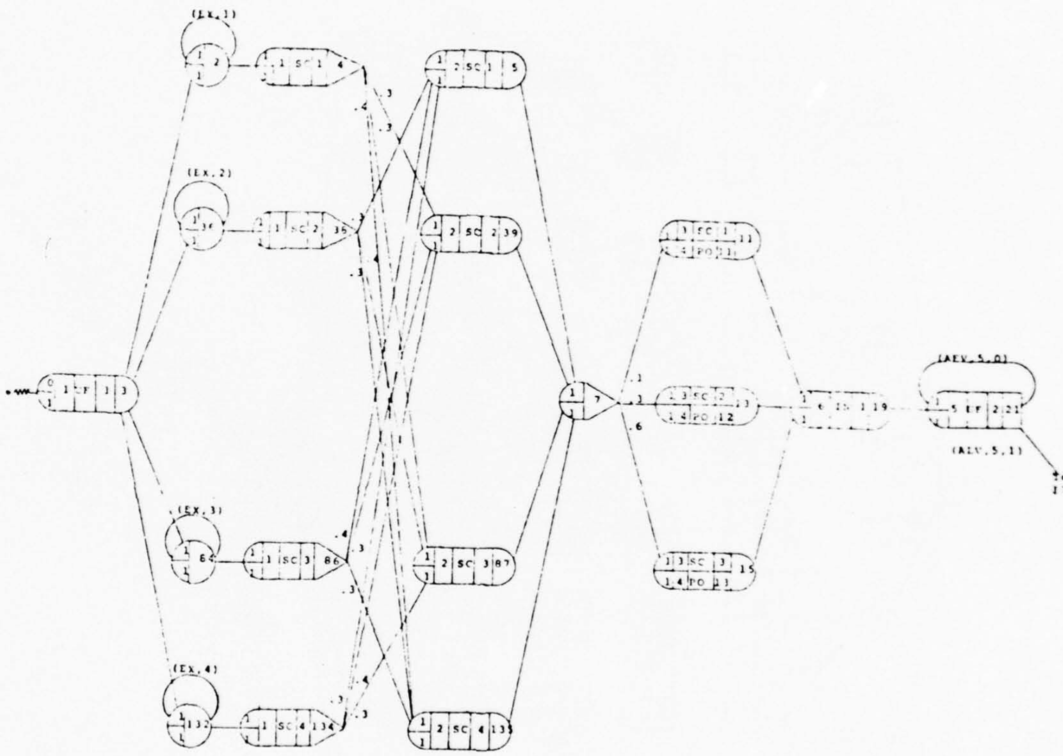
all types of message. Each packet requires 2 time units for transmission. The average variable transmission time per message is therefore 10 time units, which is comparable to the variable transmission time for messages in the message-switched network.

In order to develop a model of a packet-switched network, it is necessary to make use of the user-written FORTRAN function USERF, which was discussed previously. This function is used to separate the messages into packets prior to transmission and to reassemble the packets when transmission is completed. A complete QGERT model of the four-node packet-switched network is presented in Figure 13. Once again, part (a) of the model represents message generation and attribute assignment; part (b) represents routing and transmission of messages; and part (c) represents the collection of statistics reflecting the performance of the network.

Part (a) of Figure 13 is very similar to part (a) of the message-switched model, except for a few minor changes. As in the message-switched model, attributes 3 and 4 are assigned at nodes 11, 13, and 15. Attribute 3 still represents the priority level of the message, but attribute 4 is now assigned a value equal to the number of packets in the message. The distribution code is PO for poisson, with parameter sets 11, 12, and 13 for priority 1, 2, and 3 messages respectively. Following the assignment of

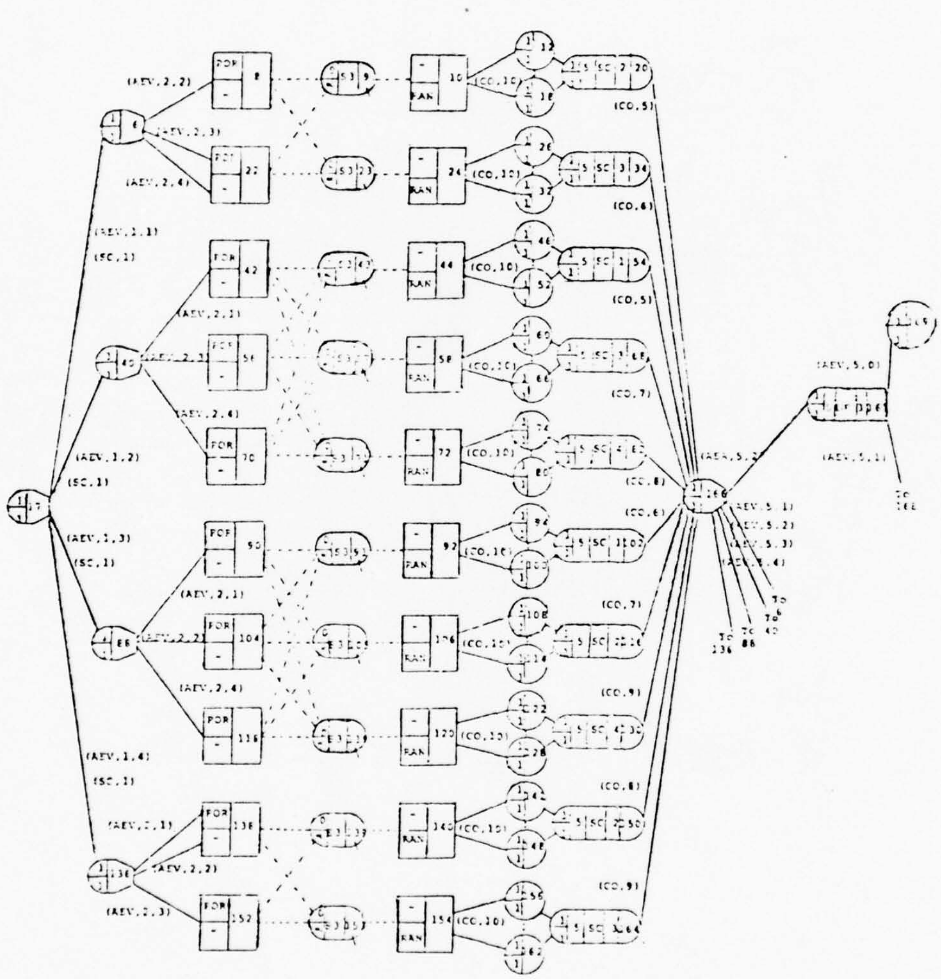
QGERT Model of a Four-Node Packet-Switched Communication Network: Message Generation

FIGURE 13(a)

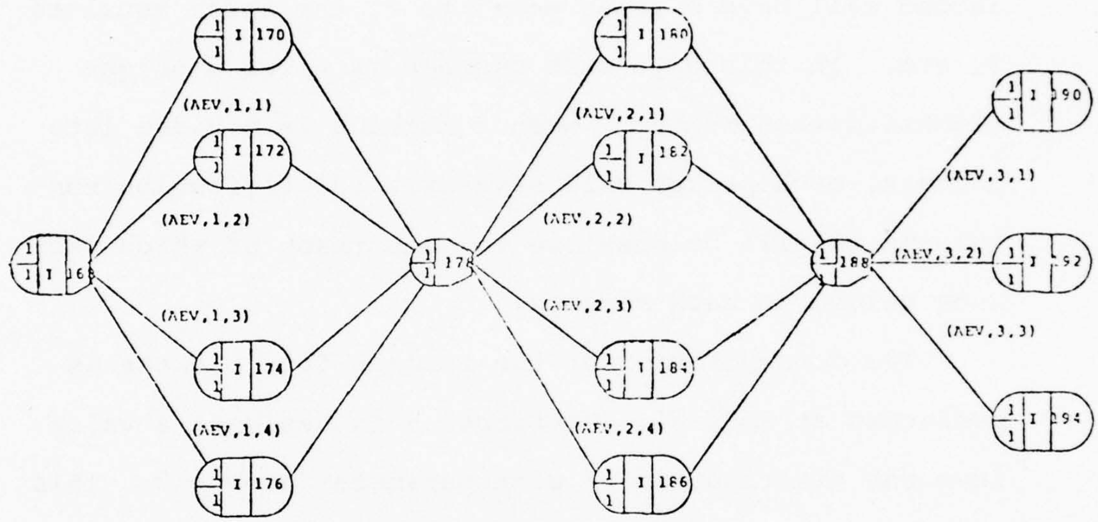


QGERT Model of a Four-Node Packet-Switched Communication Network: Routing and Transmission

FIGURE 13(b)



QGERT Model of a Four-Node Packet-Switched Communication Network: Statistics Collection



attributes 3 and 4, all messages are sent to node 19 where a value is assigned from an incremental distribution (IN) beginning with the number 1. This means that the first message will have a value of attribute 6 equal to 1, the second will have a value equal to 2, the third equal to 3, etc. In this way, each message is given a unique identification number. When a message is divided into packets, each packet will have this identification number and it will be possible to keep track of which packets belong to each message.

The decomposition of the message into packets is performed at node 21. Attribute 5 is assigned a value from the distribution UF with parameter number 2. This means that the function USERF will be called with an argument of 2. A listing of the USERF is presented in Figure 14. Initialization of variables is performed first. This occurs at node 3 where USERF is called with an argument of 1. When the number 2 is specified as an argument, packet generation takes place beginning with statement number 20. When a packet is generated, a comparison is made to see if all of the packets in the message have been generated. If they have, a value of 1 is returned for USERF. Otherwise, a value of 0 is returned. The branching from node 21 is conditional-take-first based on this value of USERF. The activity feeding back to node 21 will take place until all of the packets have

FORTRAN Function USERF for the Packet-Switched Model

FIGURE 14.

```
      FUNCTION USERF(IFN)
      COMMON/TRANS/DESCR(2000),KNOD,MFAD,NDE,NDPTH,NESTA(600)
      COMMON/PARM/ATRIB(1),ISEED,JTRIB(6),NPRMS,PARAM(100,4),SCALE
      COMMON/GENL/IFIN,IFRST,IGRAF,ITRAC,LIST80,MON,NAME(12),NORDR,NDAY,
     1 NNM,NPRNT,NPROJ,NRUN,NRUNS,NSORC(20),NTRCS,NTRCE,NSOC,NYR,TBEG,
     2 TNOW
      COMMON/USER/MESNUM(40),NPKTS(40),NMAX,KOUNT
      GO TO (10,20,30) IFN
 10   NMAX=40
      KOUNT=0
      DO 1 I=1,NMAX
      NPKTS(I)=0
      MESNUM(I)=0
 1    CONTINUE
      USERF=0.
      RETURN
 20   I=JTRIB(6)
      J=DESCR(I+3)
      KOUNT=KOUNT+1
      IF(KOUNT.EQ.J)GO TO 2
      USERF=0.
      RETURN
 2    KOUNT=0
      USERF=1.
      RETURN
 30   K=JTRIB(6)
      ID=DESCR(K+5)
      NTOTAL=DESCR(K+3)
      IF(NTOTAL.NE.1)GO TO 7
      USERF=1.0
      RETURN
 7    DO 3 I=1,NMAX
      IF(MESNUM(I).EQ.ID)GO TO 5
 3    CONTINUE
      DO 4 J=1,NMAX
      IF(MESNUM(J).NE.0)GO TO 4
      MESNUM(J)=ID
      NPKTS(J)=1
      USERF=0.
      RETURN
 4    CONTINUE
      WRITE(NPRNT,100)
 100  FORMAT(///,5X,' WARNING - PACKET ASSEMBLY AREA IS FULL',//)
      DO 300 I=1,NMAX
 300  WRITE(NPRNT,400)I,MESNUM(I),NPKTS(I)
 400  FORMAT(1X,3I10)
      CALL EXIT
 5    NPKTS(I)=NPKTS(I)+1
      IF(NPKTS(I).EQ.NTOTAL)GO TO 6
      USERF=0.
      RETURN
 6    MESNUM(I)=0
      NPKTS(I)=0
      USERF=1.
      RETURN
      END
```

been generated. The individual packets are sent to node 17 and are subsequently treated in the same way as messages in a message-switched system.

The routing and transmission section of the model (Figure 13b) is also very similar to the message-switched model. One of the differences is that the activity time on the service activities is changed to (CO,10). This implies that the transmission time of packets is constant with a value in parameter set number 10. The other change is that nodes 167 and 169 have been added to accommodate the assembly of packets prior to statistics collection. Whenever a packet arrives at node 167, USERF is called with an argument of 3. A check is made to see if it is the last of the packets to arrive for a particular message. The message identification number (attribute 6) is used for this purpose. If it is the last packet, message transmission is complete and the message is sent to node 168 for statistics collection. Otherwise, it is sent to node 169 and is stored until the remainder of the packets arrive. The statistics section of the model is exactly the same as in the message-switched model. Once again, statistics are collected for message transmission times broken down by source, destination, and priority of messages. A complete listing of the Q-GERTS output for the packet-switched network can be found in Appendix E.

Simulation Results

The results of 1 simulation of the packet-switched network shown in Figure 13 are as follows:

1) Average Message Transmission Time

Message Type	Node No.	No. of Time Units
Priority 1	190	7.7014
Priority 2	192	9.4752
Priority 3	194	20.0360
Source 1	170	22.2323
Source 2	172	9.3886
Source 3	174	10.0729
Source 4	176	19.0693
Destination 1	180	17.8812
Destination 2	182	13.7646
Destination 3	184	12.7050
Destination 4	186	17.9465
All Messages	168	15.2999

2) Average Number in Message Queues

Communication Link	Node No.	Avg. No. in Queue
1 to 2	9	2.1586
1 to 3	23	34.6291
2 to 1	43	5.2832
2 to 3	57	3.1106
2 to 4	71	.8409
3 to 1	91	2.7815
3 to 2	105	2.0000
3 to 4	119	20.2406

4 to 2	139	66.1192
4 to 3	153	1.3979

3) Average Channel Utilization

Communication Link	Activity No.	Percent Busy Time
1 to 2	198	.3400
	197	.3600
	196	.3600
	195	.3600
1 to 3	194	1.0000
	193	1.0000
	192	1.0000
	191	1.0000
2 to 1	190	.8800
	189	.8175
	188	.8461
	187	.8575
2 to 3	186	.5867
	185	.6467
	184	.6667
	183	.6467
2 to 4	182	.3400
	181	.4000
	180	.3400
	179	.3400
3 to 1	178	.4343
	177	.4543
	176	.4343
	175	.4743

3 to 2	174	.5078
	173	.5478
	172	.5000
	171	.5600
3 to 4	170	.9400
	169	.9400
	168	.9521
	167	.9790
4 to 2	166	1.0000
	165	1.0000
	164	1.0000
	163	1.0000
4 to 3	162	.5098
	161	.4898
	160	.5498
	159	.5098

Packet-Switching vs. Message Switching

The parameters of the four-node communication network were kept the same for the message-switched and packet-switched models. One of the reasons for this was to be able to make a comparison between the two systems with regards to performance. The average message transmission times for the simulation of the packet-switched network are reprinted in Table 1 along with the results for the message-switched network.

It can be seen that transmission times for the high and middle priority messages were significantly better

for the packet-switched model while the time for the low priority messages was slightly worse. The average time for all messages was approximately 15% less with packet-switching. This is as expected. Because of the pipe-lining effect, several packets of the same message can be in transmission simultaneously along parallel communication channels. As a result, the transmission times of 7.7014 for priority 1 messages and 9.4752 for priority 2 messages for the packet-switched network are actually less than the expected value of 10 for the sum of the packet transmission times (5 packets per message multiplied by 2 time units per packet).

In both of the models, the transmission times are greatest for the messages that originate at stations 1 and 4 and for those that arrive at these same stations. This is also as anticipated since there is no direct link between the two. The average queue lengths and channel utilization were significantly larger for the packet-switched model because, on the average, five times as many transactions were being placed in the system at any given time.

Table 1: Comparison of Simulated Message Transmission Times for the Packet-Switched and Message-Switched Model

Message Type	Packet-Switched	Message-Switched
	Average Transmission Time Units	
Priority 1	7.7014	12.3361
Priority 2	9.4752	16.0297
Priority 3	20.0360	19.3908
Source 1	22.2323	27.2049
Source 2	9.3886	12.3500
Source 3	10.0729	14.0068
Source 4	19.0693	17.1912
Destination 1	17.8812	17.4733
Destination 2	13.7646	13.2201
Destination 3	12.7050	15.1907
Destination 4	17.9465	25.4596
All Messages	15.2999	17.7135

Modelling Circuit-Switched Communication Networks with GASP-IV

An attempt was made to develop QGERT models similar to the ones in the previous two chapters that would accommodate circuit-switched communication networks. The models became so complex and cumbersome, however, that it was determined that QGERT would not be an effective tool for modelling these types of networks. Instead, a GASP-IV model was developed to analyze circuit-switched networks in terms of the measure of effectiveness developed by Podell and described in the introduction of this report.

The model that was developed yields the following statistics for every combination of source, destination, and priority of messages:

1. Calls attempted during the simulation
2. Calls preempted by subscribers of higher priority
3. Calls dropped because of equipment failure
4. Calls blocked by faulty equipment or higher priority calls

GASP-IV can be used for discrete or continuous simulation or a hybrid of the two. This particular model utilizes only the discrete, event-oriented features of GASP-IV. A complete listing of the program can be found in APPENDIX

F. The input to the model consists of parameters describing the network configuration and message traffic characteristics. The format of the input is presented in TABLE 2. The program output consists of an echo check of the input and the statistics described above concerning network performance.

To demonstrate the use of the program, the five-node circuit-switched communication network shown in FIGURE 15 was modelled. The simulation was carried out for a period of 300 time units with statistics being collected for the last 250 time units. The echo check of the input to the program along with a sample of the output can be found in APPENDIX G.

Five-Node Circuit-Switched Communication Network

Figure 15.

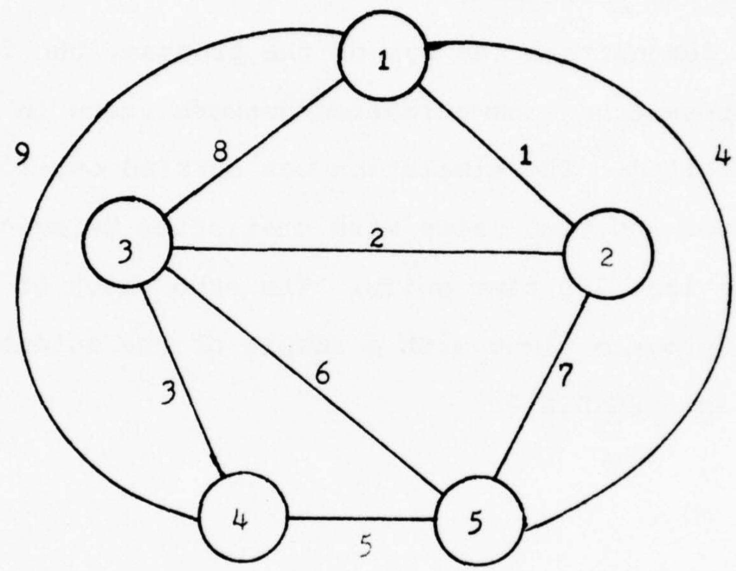


TABLE 2: INPUT FORMAT FOR
CIRCUIT SWITCHING MOE PROGRAM
(ALL INPUT RIGHT JUSTIFIED)

CARD 1

Col.	1-5	# of nodes
	6-10	# of links
	11-18	length of simulation in minutes
	19-26	length of initialization run in minutes (50.0 minutes is suggested)

(Cards 2-5 are repeated for each node)

CARD 2

Col.	1-10	Interarrival time between calls in minutes
	11-20	Average duration of calls in minutes

CARD 3

Col.	1-5	Probability	of	priority	1	calls
	6-10	"	"	"	2	"
	11-15	"	"	"	3	"
	16-20	"	"	"	4	"
	21-25	"	"	"	5	"

CARD 4

Col.	1-5	Destination node
	5-10	Probability of a call seeking this destination
	11-15	Number of alternate routes

CARD 5 (1 card for each route in order of preference)

Col.	1-5	1st link of the route
	6-10	2nd link of the route,
	:	etc.
	:	
	36-40	

Return to Card 4 until all destinations are considered. Insert a card with a-1 in Cols. 4-5 to mark end of input for this node.

Return to Card 2 until input for all nodes has been considered. (Input one card 6 for each link).

CARD 6

Col.	1-5	# of lines in link
	6-13	Average time between breakdowns in minutes
	14-21	Average duration of breakdown in minutes
	22-26	(Nodes connected by
	27-31	(the link

Follow these cards by standard GASP IV input cards.

SUMMARY AND CONCLUSIONS

QGERT was found to be an effective tool for the analysis of performance of store-and-forward communication networks. In particular, once the analyst has become familiar with the QGERT symbol set and related terminology, the ease with which networks can be modelled and modified makes it quite attractive. Compared to a straight simulation, the initial model development stage requires very little time. On the other hand, the time to perform the simulation can become quite large in certain instances. This was particularly true in the case of the packet-switched model, in which a significant amount of time was required to check each packet as it arrived at its destination in the process of reassembling the packets into the original message. Limited computer resources did not permit elaborate experimentation to determine how simulation time increased with the number of nodes in the communication network. A small experiment with three, four, and five node networks, however, seemed to indicate that simulation time would not increase exponentially.

Because the QGERT models can be modified easily, they are well suited to an analysis of alternative network configurations during the design stages of communication network development. For example, the configuration and

message traffic characteristics for the sample four-node network analyzed in this thesis were selected arbitrarily. The results of the simulations indicate that there are severe imbalances and that the network is not well designed to accommodate the existing message traffic. Specifically, the links going from node 1 to node 3, node 2 to node 1, node 3 to node 4, and node 4 to node 2 are characterized by very high channel utilization rates and consequently, very long message queues. The remainder of the links, however, have relatively small utilization rates and message queues. The analyst might want to test whether or not performance of the network could be improved by adding channels to the busy lines and deleting unnecessary channels from the other lines. This can be accomplished within the framework of the QGERT model simply by adding or deleting one node and two activities for each channel. This would mean the addition or deletion of three cards from the input deck.

In the introduction to this report, it was stated that a measure of effectiveness for store-and-forward communication networks should include either estimates of the average message transmission time or the probability that a message is completed within a specified number of time units. The former can be seen directly in the form of the interval statistics collected for each of the models presented in the previous chapters, while the latter can

be determined from the histograms printed as part of the Q-GERTS output. For example, in Appendix C, the histogram for node 190 shows that 29 out of 114 high priority messages had completion times greater than 18 time units. The probability of completing a high priority message in less than 18 time units could therefore be estimated as 75% (85 divided by 114).

It was also stated that the measure of effectiveness should include the probability of balking and the probability of messages being preempted by subscribers of higher precedence. The latter was not included in the models of message-switched and packet-switched networks presented previously, but is discussed in the following section entitled Areas for Further Study. In the message-switched model with limited queue lengths, the output of which can be found in Appendix C, the probability of balking can be estimated from the Q-GERTS summary report. This report shows, for each of the types of messages, the total number that balked and the total number that were completed. The probability of balking can therefore be estimated by dividing the number of balkers by the total number of messages.

QGERT was not found to offer any advantages in the modelling of circuit-switched networks. Instead, a GASP-IV program was developed to estimate performance

measures for networks of this type. The program calculates the various components of the measure of effectiveness formulated by Podell for circuit-switched networks. Simulation time does not grow exponentially as the size of the network increases.

Areas For Further Study

The QGERT modelling technique has been shown to offer several advantages over other simulation techniques in the modelling of certain types of store-and-forward communication networks. There are a number of things that can still be done, however, to make the modelling effort more efficient and general enough to accommodate any store-and-forward network.

There is, at the time of this writing, an improved version of QGERT being developed. This new version will contain several features which will simplify the modelling of communication networks considerably. For one thing, parallel servers can be modelled with a single activity indicating the number of servers. This means that for each of the communication lines in the network, a single activity can replace the symbol set developed for a communication line in Figure 6. This really becomes significant for lines which contain a large number of communication channels. Another feature offered by the new version is the duplication of similar parts of a QGERT model. This would be very beneficial in the modelling of large communication networks, particularly in the routing and transmission section of the model which is characterized by a series of similar subnetworks

representing the communication lines. Also, a set of subroutines will be available for use in the user functions. The subroutines will permit the addition of much more advanced logic in the models. For example, one of the subroutines can be used to account for preemption of low priority messages in the models of communication networks.

After the new version of QGERT is fully tested and made available for commercial use, it is recommended that the following experiments be carried out:

1. The testing of various routing strategies for messages or packets. This can be accomplished in part by changing the queue selection rules in the S-nodes of the message-switched and packet-switched models. QGERT offers a limited number of such rules. An elaborate strategy might require some modification of the coding in the Q-GERTS program.
2. Experimentation to determine the optimum number of simulations and the length of the simulations in order to establish levels of statistical confidence for the different types of performance measures being investigated in the models.
3. Modelling of existing communication networks such as the packet-switched ARPANET and the message-switched AUTODIN network of the Department of

Defense in order to determine how well the models reflect the actual performance of these networks.

The research described in this paper has taken into consideration message-switched, packet-switched, and circuit-switched communication networks. These are the types of networks that are commonly used in the world today. New networks are currently being developed, however, which represent a hybrid of these three types. In particular, a network might be developed to accommodate voice messages in a circuit-switched manner, with packets of data being transmitted over the communication lines during pauses in the conversation. The ultimate goal of the type of modelling described in this report would be the development of a specialized network technique which would be able to simulate any type of communication network.

BIBLIOGRAPHY

1. Davies, D. W. and D. L. A. Barber, Communication Networks for Computers, John Wiley and Sons, Inc. (1973).

2. Elmaghraby, S. E., "An Algebra for the Analysis of Generalized Activity Networks," Management Science, 10, 3 pp. 494-514 (1964).

3. Eisner, H., "Generalized Network Approach to the Planning and Scheduling of a Research Program," Operations Research, 10, 1 pp. 115-125 (1962).

4. Fagan, J. J. and G. E. Whitehouse, "An Investigation of the Use of Stochastic Network Theory to Model Communication Networks." A paper presented at the ORSA Conference in Miami Beach, Florida (November, 1976).

5. Fischer, M. J. and J. E. Knepley, "Circuit Switched Network Performance Algorithm (MODI)," DCASEF Technical Note 1-73, (January 1973).

6. Harvey, J. F. and R. D. Shults, "Transition Performance Allocation Program (ALAMO)," Project 2JBC, Functional Description (1 October 1974).

7. Harvey, J. F., R. L. Podell, R. D. Shults, "Evaluation of Measure of Effectiveness," Functional Description, Project 2JBP (8 January 1975).

8. Hogg, G. L., D. T. Phillips, M. J. Maggard, and W. G. Lesso, "GERTS QR: A Model for Multi-Resource Constrained Queueing Systems - Part I," AIIE Transactions, 7, 2 (1975).

9. Hogg, G. L., et al., "GERTS QR: A Model for Multi-Resource Constrained Queueing Systems, Part II: An Analysis of Parallel-Channel, Dual-Resource Constrained Queueing Systems with Homogeneous Resources," submitted to AIIE Transactions, 7, 2 (1975).

10. Kleinrock, L., Communication Nets: Stochastic Message Flow and Delay, Dover Publications, Inc. (1964).

11. Kleinrock, L., Queueing Systems - Volume II: Computer Applications, John Wiley and Sons, Inc. (1976).

12. Maggard, M. J., et al., "Network Analysis with GERTS IIIQR", Industrial Engineering, 6, 5 pp. 24-29 (May 1974).

13. Martin, J., Systems Analysis and Data Transmission, Prentice-Hall, Inc. (1972).

14. Martin, J., Telecommunications and the Computer, Prentice-Hall, Inc. (1969).

15. Podell, R., "A Measure of Effectiveness for a Digital Communications System," Proc. of the National Electronics Conference, p. 229 (October 1974).

16. Pritsker, A. A. B. and W. W. Happ, "GERT: Graphical Evaluation and Review Technique: Part I - Development," The Journal of Industrial Engineering, 17, 5 (May 1966).

17. Pritsker, A. A. B., The GASP IV Simulation Language, John Wiley and Sons, Inc. (1974).

18. Pritsker, A. A. B. and G. E. Whitehouse, "GERT: Graphical Evaluation and Review Technique: Part II - Probabilistic and Industrial Engineering Application," The Journal of Industrial Engineering, 17, 6 pp. 293-301 (June 1966).

19. Pritsker, A. A. B., The Q-GERT User's Manual, Pritsker and Associates, Inc. (May 1974).

20. Whitehouse, G. E. and A. A. B. Pritsker, "GERT: Part III - Further Statistical Results: Counters, Renewal Time, and Correlations," AIIE Transactions, Vol. 1, No. 1 (1969).

21. Whitehouse, G. E., Systems Analysis and Design Using Network Techniques, Prentice-Hall, Englewood Cliffs, New Jersey (1973).

22. Whitehouse, G. E., R. L. Podell, and John J. Fagan, "On the Application of Simulation to Determine MOE's for Communication Networks." A paper to be presented at the Summer Simulation Conference in Chicago, Illinois (July 1977).

Q-GERTS Output for the Sample Model in FIGURE 4

APPENDIX A

GERT SIMULATION PROJECT 1 BY J.J.FAGAN
DATE 2/ 1/1977 QGERT VERSION 6/15/75

** NETWORK DESCRIPTION **

```
NUMBER OF SINK NODES IS     1
STATISTICS COLLECTED ON     4 NODES (INCLUDING SINKS)
NUMBER OF NODES TO REALIZE THE NETWORK IS     1
NUMBER OF SIMULATIONS REQUESTED IS     5
INITIAL RANDOM NUMBER IS       2345
NUMBER OF ATTRIBUTES PER TRANSACTION IS     1
MODIFICATIONS - NO
BEGINNING, ENDING TRACE RUNS -     0,     0
SCALE FACTOR FOR SC DISTRIBUTION IS     1.0000
TIME FROM WHICH STATISTICS ARE KEPT      .0000
TYPE OF HISTOGRAM DESIRED - PLOTTED
FIRST RUN PRINTOUT OPTION - NO
LIST ALL INPUT OPTION - YES
EXECUTION OPTION - E3
```

** NODE CHARACTERISTICS **

NODE	NUMBER OF REQUIREMENTS	NO. OF SUBSEQUENT REQUIREMENTS	OUTPUT TYPE	MARK	TYPE OF STATISTICS	ATTRIBUTE CHOICE (CRITERION)	(ATTR. NO.)	HALTING DESIRED AT RELEASE
2	0	1	D	M		LAST	0	
3	0	1	D	M		LAST	0	
7	1	1	D		D	LAST	0	
8	1	1	D		I	LAST	0	
9	1	1	D		I	LAST	0	
10	0	1	D	M		LAST	0	
11	1	1	D		F	LAST	0	

```
SOURCE NODE NUMBERS
     2    3   10

SINK NODE NUMBERS
    11

STATISTICS COLLECTED ALSO ON NODES
     9    8    7
```

** QUEUE NODES **

NODE	INITIAL NO. IN QUEUE	MAXIMUM NO. ALLOWED	OUTPUT TYPE	PRIORITY SCHEME	MAY BLOCK INCIDENT SERVERS	NODE FOR BALKERS	ASSOCIATED SELECTOR
5	0	3	D	SML (1)	NO	-1	0
6	0	4	P	SML (1)	NO	-1	0

** SELECTOR NODES **

NODE	SELECTION RULES (QUEUES)	SELECTION RULES (SERVERS)	MAY BLOCK INCIDENT SERVERS	NODE FOR BALKERS	Q-NODES ASSOCIATED WITH SELECTOR
4	SNQ	POR	NO	-1	5 6

ATTRIBUTE ASSIGNMENT INFORMATION

NODE NUMBER	ATTRIBUTE NUMBER	DISTRIBUTION TYPE	PARAMETER SPECIFICATION
2	1	SC	1
3	1	SC	2

PARAMETER SPECIFICATION

PARAMETER SET	PARAMETERS 1	2	3	4
1	2.0000	.0000	9999.0000	.0000
2	2.0000	.0000	9999.0000	.0000
3	1.0000	.0000	9999.0000	.5000
4	1.0000	.0000	9999.0000	.0000
5	.0000	.5000	1.5000	.0000

** ACTIVITY DESCRIPTION **

START NODE	END NODE	DISTRIBUTION TYPE	PARAM SPEC	ACTIVITY NUMBER	COUNT TYPE	PROBABILITY	CONDITIONAL BRANCHING INFORMATION (CODE) (FIELD A) (FIELD B) (ORDER)
2	2	EX	1	0	0	1.0000	
2	4	SC	1	0	0	1.0000	
3	3	EX	2	0	0	1.0000	
3	4	SC	1	0	0	1.0000	
5	7	NO	3	198	0*	1.0000	
[illegible]	7	GO	4	197	0*	.5000	
[illegible]	7	UN	5	196	0*	.5000	
7	8	SC	0	0	0	1.0000	
7	9	SC	0	0	0	1.0000	
10	11	SC	100	0	0	1.0000	

```
*** INPUT CARDS ***

GEN,J.J.FAGAN,1,2,1,1977,1,4,1,5,2345,1*
SOU,2,0,1*
SOU,3,0,1*
SEL,4,SNQ,,,,,5,6*
QUE,5,0,3,D,S,1*
QUE,6,0,4,P,S,1*
STA,7,1,1,,B*
STA,8,1,1,,I*
STA,9,1,1,,I*
SOU,10,0,1*
SIN,11,1,1*
VAS,2,1,SC,1*
VAS,3,1,SC,2*
PAR,1,2*
PAR,2,2*
PAR,3,1,,,0.5
PAR,4,1*
PAR,5,,0.5,1.5*
ACT,2,2,EX,1*
ACT,2,4,SC,1*
ACT,3,3,EX,2*
ACT,3,4,SC,1*
ACT,5,7,NO,3*
ACT,6,7,CO,4,,.2*
ACT,6,7,UN,5,,.8*
ACT,7,8,,,,,AEV,1,1*
ACT,7,9,,,,,AEV,1,2*
ACT,10,11,SC,100*
FIN*

*** NO ERRORS DETECTED IN INPUT DATA ***

*** EXECUTION WILL BE ATTEMPTED ***
```

GERT SIMULATION PROJECT 1 BY J.J.FAGAN
DATE 2/ 1/ 1977

FINAL RESULTS FOR 5 SIMULATIONS

NODE	PROBABILITY	MEAN	STD.DEV.	STD.DEV. OF MEAN	COEFF. VAR.	NO OF OBS.	MIN.	MAX.	STAT TYPE
11	1.0000	100.0000	.0000	.0000	.0000	5.	100.0000	100.0000	F
9	1.0000	2.4078	.6784	.0311	.2817	477.	1.0000	5.7722	I
8	1.0000	2.4078	.6784	.0311	.2817	477.	1.0000	5.7722	I
7	1.0000	1.0329	.9001	.0414	.8715	472.	.0013	5.6183	B

AVERAGE NUMBER IN Q-NODE

NODE NO.	MEAN	STD.DEV.	NO. OF OBS.	MIN.	MAX.
5	.3161	.0461	5.	.2586	.3731
6	.0828	.0326	5.	.0399	.1162

NUMBER IN Q-NODE

MIN.	MAX.
.	3.
.	2.

AVERAGE SERVER UTILIZATION

SERVER NO.	MEAN	STD.DEV.	NO. OF OBS.	MIN.	MAX.
198	.7025	.0277	5.	.6634	.7305
197	.2554	.0708	5.	.1534	.3467

TIME PERIODS OF SERVER

LONGEST PERIOD IDLE	LONGEST PERIOD BUSY
4.3636	12.7046
24.0544	5.7060

AVERAGE NO. BALKING PER UNIT TIME

NODE NO.	MEAN	STD.DEV.	NO. OF OBS.	MIN.	MAX.
4	.0000	.0000	5.	.0000	.0000

Q-GERTS Output for the Four-Node Message-Switched Network Model in FIGURE 8

APPENDIX B

GERT SIMULATION PROJECT 2 BY J.J.FAGAN
DATE 2/ 15/ 1977

FINAL RESULTS FOR 2 SIMULATIONS

NODE	PROBABILITY	MEAN	STD.DEV.	STD.DEV. OF MEAN	COEFF. VAR.	NO OF OBS.	MIN.	MAX.	STAT TYPE
173	1.0000	300.0000	.0000	.0000	.0000	2.	300.0000	300.0000	F
194	1.0000	19.3909	18.3153	.6978	.9445	689.	2.1566	135.6106	I
192	1.0000	16.0297	14.1499	.7731	.8827	335.	2.3507	93.5716	I
190	1.0000	12.3361	8.0870	.7711	.6556	110.	2.1576	38.9095	I
188	1.0000	25.4596	24.2074	1.4678	.9508	272.	2.1772	135.6106	I
184	1.0000	15.1907	12.1693	.6958	.8011	305.	2.5167	62.0796	I
182	1.0000	13.2201	10.1949	.6054	.7714	283.	2.1576	64.9573	I
180	1.0000	17.4733	14.0369	.8480	.8033	274.	3.7711	93.5716	I
176	1.0000	17.1912	14.4635	.8364	.8413	299.	2.1576	93.5716	I
174	1.0000	14.0068	9.5850	.5844	.6843	269.	2.5736	52.3629	I
172	1.0000	12.3500	8.7076	.5167	.7051	284.	2.1772	52.6115	I
170	1.0000	27.2049	24.2385	1.4434	.8910	282.	3.5090	135.6106	I
158	1.0000	17.7135	16.5641	.4919	.9351	1134.	2.1576	135.6106	I

AVERAGE NUMBER IN Q-NODE / **NUMBER IN Q-NODE**

NODE NO.	MEAN	STD.DEV.	NO. OF OBS.	MIN.	MAX.	MIN.	MAX.
9	.0154	.0217	2.	.0000	.0307	.	1.
23	3.7137	.5604	2.	3.3391	4.0392	.	14.
43	.4964	.4217	2.	.1982	.7945	.	5.
57	.0653	.0373	2.	.0359	.0923	.	2.
71	.0000	.0000	2.	.0000	.0000	1.	1.
91	.0552	.0719	2.	.0044	.1061	.	2.
105	.0047	.0066	2.	.0000	.0094	.	1.
119	2.1353	.8560	2.	1.5300	2.7406	.	12.
139	1.7557	.5175	2.	1.3999	2.1216	.	9.
153	.0958	.0119	2.	.0874	.1042	.	3.

		AVERAGE SERVER UTILIZATION				**TIME PERIODS OF SERVER**	
SERVER NO.	MEAN	STD.DEV.	NO. OF OBS.	MIN.	MAX.	LONGEST PERIOD IDLE	LONGEST PERIOD BUSY
199	.2409	.0444	2.	.2087	.2714	75.2513	16.5149
197	.3546	.0542	2.	.3163	.3930	45.9706	16.2108
196	.3673	.1590	2.	.2543	.4797	99.8927	44.1325
195	.4055	.1768	2.	.2319	.5791	72.7551	37.8505
194	.9067	.0095	2.	.9000	.9134	6.9551	152.7589
193	.9169	.0622	2.	.8729	.9608	11.2337	156.0063
192	.8631	.0014	2.	.8621	.8641	13.9323	156.5195
191	.9068	.0141	2.	.8998	.9198	10.9773	159.1455
190	.6405	.1569	2.	.5296	.7515	13.4599	72.8793
189	.6393	.1395	2.	.5412	.7385	23.6724	37.5805
188	.6043	.0365	2.	.5798	.6287	25.7081	[illegible]
187	.7193	.1898	2.	.5851	.8335	21.8726	52.0425
186	.4584	.1037	2.	.3249	.5419	25.4129	37.5596
185	.5523	.0830	2.	.4936	.6109	23.1775	51.7705
184	.4090	.0039	2.	.4053	.4106	45.5536	27.5815
183	.4315	.0725	2.	.4302	.5327	49.8919	24.3135
182	.3320	.1310	2.	.2394	.4247	89.2553	74.2527
181	.4933	.1721	2.	.2322	.5255	57.5640	77.2260
180	.2934	.0249	2.	.2632	.3035	51.2314	27.5961
179	.3909	.1293	2.	.2994	.4823	33.9307	43.2729
178	.3933	.2720	2.	.2010	.5857	44.3424	33.7423
177	.4717	.0787	2.	.4161	.5273	47.3953	31.9515
176	.4371	.1236	2.	.3455	.5237	50.1415	72.3585
175	.5121	.0919	2.	.4471	.5771	22.7195	31.5459
174	.3530	.1308	2.	.2605	.4455	31.1334	24.3373
173	.3407	.1697	2.	.2258	.4557	72.4969	44.8168
172	.4700	.2334	2.	.3050	.5351	51.2371	45.2521
171	.5129	.0361	2.	.2973	.7384	71.7196	30.7135
170	.7801	.0550	2.	.7412	.8130	27.5301	101.8292
169	.8230	.0323	2.	.7574	.8832	14.9279	97.7330
168	.8715	.0157	2.	.8704	.8825	13.9139	141.7665
167	.7987	.0869	2.	.7372	.8602	29.5147	115.1277
166	.8117	.0772	2.	.7569	.8651	20.0174	97.2556
165	.8177	.1369	2.	.7203	.9144	27.2234	95.3992
164	.8731	.0578	2.	.8322	.9142	15.1577	57.5149
163	.9093	.0303	2.	.3794	.9022	13.5511	37.1514
162	.4430	.1171	2.	.3572	[illegible]	16.3157	37.7774
161	.5347	.1139	2.	.4442	.6032	[illegible]	57.4705
160	.4027	.0877	2.	.3507	.4747	122.3757	41.3571
159	.4255	.2612	2.	.2409	.6104	54.2093	26.1769

Q-GERTS Output for the Message-Switched Model with Balking

APPENDIX C

AD-A041 314 LEHIGH UNIV BETHLEHEM PA DEPT OF INDUSTRIAL ENGINEERING F/G 17/2
EXTENSIONS OF STOCHASTIC NETWORK THEORY TO FACILITATE THE DEVEL--ETC(U)
1977 G E WHITEHOUSE, J J FAGAN N00014-76-C-0900

UNCLASSIFIED IE-77-OR-1 NL

2 OF 2
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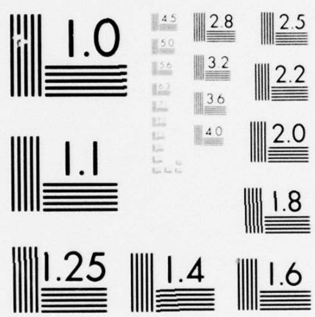
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2.8
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3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

CERT SIMULATION PROJECT 2 BY J.J.FAGAN
DATE 2/ 15/ 1977

FINAL RESULTS FOR 2 SIMULATIONS

NODE	PROBABILITY	MEAN	STD.DEV.	STD.DEV. OF MEAN	COEFF. VAR.	NO OF OBS.	MIN.	MAX.	STAT TYPE
173	1.0000	300.0000	.0000	.0000	.0000	2.	300.0000	300.0000	F
199	1.0000	2.7373	4.6204	.8169	1.7066	32.	1.0000	18.5215	I
195	1.0000	2.7912	4.5811	1.0510	1.6413	19.	1.0000	17.8095	I
193	1.0000	3.5031	6.6225	2.5031	1.8905	7.	1.0000	18.5215	I
191	1.0000	1.5131	1.2564	.5131	.8306	6.	1.0000	4.0787	I
194	1.0000	17.1150	13.6880	.5222	.7998	687.	2.1656	96.9495	I
192	1.0000	14.9537	11.2990	.6239	.7556	328.	2.2980	91.0762	I
190	1.0000	14.7561	11.5312	1.0800	.7815	114.	2.1241	67.2738	I
186	1.0000	18.8156	15.1713	.9132	.8063	276.	2.3321	96.9495	I
184	1.0000	14.9575	11.3885	.6910	.7614	271.	2.5351	64.6007	I
182	1.0000	12.4971	10.5359	.6263	.8431	283.	2.1241	62.6251	I
180	1.0000	18.6011	12.8355	.7423	.6900	299.	4.0873	67.2733	I
176	1.0000	16.0401	12.9594	.7887	.8079	270.	2.1241	67.2738	I
174	1.0000	15.0078	10.8892	.6318	.7255	297.	3.4012	53.5045	I
172	1.0000	13.6708	10.9319	.6521	.7997	281.	2.3321	66.8603	I
170	1.0000	20.3393	15.3358	.9149	.7540	281.	3.5204	96.9495	I
168	1.0000	16.2489	12.8625	.3828	.7916	1129.	2.1241	96.9495	I

AVERAGE NUMBER IN Q-NODE **NUMBER IN Q-NODE**

NODE NO.	MEAN	STD.DEV.	NO. OF OBS.	MIN.	MAX.	MIN.	MAX.
9	.0233	.0110	2.	.0125	.0250	.	1.
23	1.0440	.2724	2.	1.4510	1.0359	.	5.
43	.4618	.1700	2.	.3416	.5820	.	5.
57	.1199	.0175	2.	.1075	.1323	.	2.
71	.0718	.1015	2.	.0030	.1436	.	3.
91	.5570	.0559	2.	.5175	.5965	.	5.
105	.0015	.0022	2.	.0030	.0031	.	1.
119	.5835	.0992	2.	.5129	.6532	.	5.
133	.5063	.6317	2.	.0596	.9530	.	4.
153	.0169	.0239	2.	.0000	.0338	.	1.

AVERAGE SERVER UTILIZATION **TIME PERIODS OF SERVER**

SERVER NO.	MEAN	STD.DEV.	NO. OF OBS.	MIN.	MAX.	LONGEST PERIOD IDLE	LONGEST PERIOD BUSY
198	.4974	.1048	2.	.4208	.5745	29.8442	24.5981
197	.4238	.0875	2.	.3598	.4827	56.6419	45.8474
196	.3437	.1026	2.	.2772	.4222	40.7910	33.6709
195	.2641	.1492	2.	.1593	.3689	57.7442	23.5044
194	.8169	.1563	2.	.6966	.9173	13.3423	84.0777
193	.8633	.0802	2.	.8066	.9200	12.3097	84.0028
192	.8191	.1499	2.	.7137	.9244	15.1243	80.0552
191	.8472	.1135	2.	.7634	.9310	12.5014	67.2417
190	.6444	.0507	2.	.6105	.6822	27.6310	41.2329
189	.6330	.1856	2.	.5018	.7643	24.6341	41.5930
188	.5440	.0378	2.	.6178	.6702	25.3877	30.8454
187	.6594	.1746	2.	.5333	.7828	19.9655	48.6376
186	.6450	.0227	2.	.6240	.6611	12.3977	55.6555
185	.6323	.1380	2.	.5344	.7295	32.4368	41.0370
184	.5468	.0265	2.	.5680	.6056	30.6087	48.4520
183	.7695	.1470	2.	.6657	.8736	16.5942	84.7622
182	.3075	.0637	2.	.2624	.3526	77.1113	18.0588
181	.2952	.1033	2.	.2221	.3682	94.3326	31.8733
180	.2808	.0877	2.	.2578	.3518	65.1241	24.5916
179	.2863	.1568	2.	.1555	.3772	87.9557	20.6725
178	.6270	.0353	2.	.6233	.6327	35.8122	69.7879
177	.5934	.0303	2.	.5720	.6148	29.9325	82.9170
176	.6525	.0137	2.	.6823	.7022	22.9201	61.3562
175	.4854	.0166	2.	.6731	.6958	27.9754	91.4431
174	.3340	.1564	2.	.2277	.4403	52.1333	23.3570
173	.2934	.1052	2.	.2240	.3728	96.5352	31.8981
172	.4778	.0519	2.	.4413	.5142	60.1026	35.3311
171	.3010	.0832	2.	.2421	.3596	73.6956	25.3384
170	.7990	.0720	2.	.7437	.8453	16.1490	40.1272
169	.8563	.0323	2.	.8987	.5680	14.4313	45.5439
168	.7262	.0606	2.	.6775	.7629	19.5234	53.5381
167	.7773	.1327	2.	.6827	.8718	22.0734	63.7657
166	.6859	.2275	2.	.5250	.8467	24.1979	51.3574
165	.7422	.1220	2.	.6560	.8285	31.0476	40.8624
164	.7557	.2512	2.	.5781	.9333	32.6377	70.0011
163	.6663	.2662	2.	.4780	.8545	18.9531	53.5373
162	.3592	.1037	2.	.2758	.4225	49.2095	46.3049
161	.2446	.1110	2.	.2094	.3677	50.0668	33.2203
160	.3976	.1112	2.	.3187	.4760	45.7049	27.7919
159	.4518	.2275	2.	.2909	.6126	60.6782	27.6751

AVERAGE NO. BALKING PER UNIT TIME

NODE NO.	MEAN	STD.DEV.	NO. OF OBS.	MIN.	MAX.
23	.0000	.0000	2.	.0000	.0000
43	.0000	.0000	2.	.0000	.0000
119	.0000	.0000	2.	.0000	.0000
133	.0000	.0000	2.	.0000	.0000
5	.0000	.0000	2.	.0000	.0000
22	.0000	.0000	2.	.0000	.0000
42	.0000	.0000	2.	.0000	.0000
55	.0000	.0000	2.	.0000	.0000
73	.0000	.0000	2.	.0000	.0000
93	.0000	.0000	2.	.0000	.0000

HISTOGRAMS

NODE	LOWER LIMIT	CELL WIDTH	FREQUENCIES										
173	.00	1.00	0	0	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	2		
198	.00	1.00	0	27	0	0	0	1	0	0	1	0	0
			0	1	0	0	0	0	0	1	1		
195	.00	1.00	0	16	0	0	0	0	0	0	1	0	0
			0	1	0	0	0	0	0	1	0		
193	.00	1.00	0	6	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	1		
191	.00	1.00	0	5	0	0	0	1	0	0	0	0	0
			0	0	0	0	0	0	0	0	0		
194	.00	1.00	0	0	0	15	31	45	36	33	35	44	29
			34	25	19	18	20	25	19	22	233		
192	.00	1.00	0	0	0	4	14	22	24	15	27	23	18
			10	13	[illegible]	13	12	11	8	8	93		
190	.00	1.00	0	0	0	5	7	5	8	6	5	5	5
			4	5	8	5	3	7	3	4	29		
186	.00	1.00	0	0	0	6	9	15	13	9	17	17	13
			5	10	5	12	10	16	3	11	133		
184	.00	1.00	0	0	0	5	19	19	12	17	12	19	11
			21	10	15	9	8	4	6	4	60		
182	.00	1.00	0	0	0	13	24	21	25	22	25	20	13
			11	8	5	4	6	13	9	7	57		
180	.00	1.00	0	0	0	0	0	17	18	11	13	16	17
			11	15	10	11	11	10	12	12	115		
176	.00	1.00	0	5	0	18	19	13	8	15	15	19	9
			13	8	11	2	6	9	8	6	91		
174	.00	1.00	0	0	0	0	14	21	28	17	26	16	15
			8	12	5	8	10	13	8	9	87		
172	.00	1.00	0	0	0	6	12	26	20	18	15	18	16
			16	12	14	16	10	11	7	6	56		
170	.00	1.00	0	0	0	0	7	12	12	9	11	19	11
			11	11	5	10	9	10	7	13	124		
168	.00	1.00	0	0	0	24	52	72	68	59	67	72	51
			48	43	35	36	35	43	30	34	360		
9	.00	1.00	0	2	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0		
23	.00	1.00	0	0	2	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0		
43	.00	1.00	0	2	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0		

FORTRAN Function USERF for the Message-Switched Model
with Generalized Message Generation

APPENDIX D

```
      FUNCTION USERF(IFN)
      DIMENSION PDES(4,4),PPRI(4,3),TIME(4,3)
      COMMON/PARM/ATRIB(1),ISEED,JTRIB(6),NPRMS,PARAM(100,4),SCALE
      DATA((PDES(I,J),J=1,4),I=1,4)/0.,.3,.3,.4,.3,0.,.4,.3,.4,.3,0.,.3,
     1 .3,.4,.3,0./
      DATA((PPRI(I,J),J=1,3),I=1,4)/.1,.3,.6,.1,.4,.5,.2,.3,.5,.1,.2,.7/
      DATA((TIME(I,J),J=1,3),I=1,4)/5.,7.,10.,6.,8.,10.,8.,9.,12.,5.,
     1 8.,10./
      NSOU=JTRIB(1)
      RN=DRAND(ISEED)
      CUMPROB=0.
      GO TO(1,2,3)IFN
1     DO 10 J=1,4
      IF(NSOU.EQ.J)GO TO 10
      CUMPROB=CUMPROB+PDES(NSOU,J)
      IF(RN.LT.CUMPROB)GO TO 11
10    CONTINUE
11    IDES=J
      USERF=IDES
      RETURN
2     DO 20 J=1,3
      CUMPROB=CUMPROB+PPRI(NSOU,J)
      IF(RN.LT.CUMPROB)GO TO 21
20    CONTINUE
21    IPRI=J
      USERF=IPRI
      RETURN
3     USERF=-TIME(IDES,IPRI)*ALOG(RN)
      RETURN
      END
```

Q-GERTS Output for the Four-Node Packet-Switched Network Model in FIGURE 13

APPENDIX E

GERT SIMULATION PROJECT 3 BY J.J.FAGAN
DATE 3/ 1/ 1977

FINAL RESULTS FOR 1 SIMULATIONS

NODE	PROBABILITY	MEAN	STD.DEV.	STD.DEV. OF MEAN	COEFF. VAR.	NO OF OBS.	MIN.	MAX.	STAT TYPE
173	1.0000	150.0000	.0000	.0000	.0000	1.	150.0000	150.0000	F
194	1.0000	20.0360	17.7111	1.4608	.8840	147.	4.0000	71.7300	I
192	1.0000	9.4752	4.1355	.4539	.4364	93.	4.0000	25.4313	I
190	1.0000	7.7014	2.1595	.4081	.2804	28.	4.0000	14.0198	I
186	1.0000	17.9465	16.0748	2.0094	.8957	64.	4.0000	71.2727	I
184	1.0000	12.7050	10.5070	1.2298	.8270	73.	4.5000	52.3942	I
182	1.0000	13.7646	13.8055	1.6384	1.0030	71.	4.7550	52.3370	I
180	1.0000	17.6812	18.0963	2.5592	1.0120	50.	5.5000	71.7300	I
176	1.0000	19.0693	19.5987	2.3425	1.0278	70.	4.5000	71.7300	I
174	1.0000	10.0729	5.7829	.7728	.5741	56.	4.5000	31.1947	I
172	1.0000	9.3886	4.8226	.5806	.5137	69.	4.0000	31.0995	I
170	1.0000	22.2323	16.6406	2.0965	.7435	63.	5.5000	71.2727	I
153	1.0000	15.2999	14.6364	.9112	.9566	253.	4.0000	71.7300	I

	AVERAGE NUMBER IN Q-NODE					**NUMBER IN Q-NODE**	
NODE NO.	MEAN	STD.DEV.	NO. OF OBS.	MIN.	MAX.	MIN.	MAX.
9	2.1596	.0000	1.	2.1596	2.1596	.	15.
23	34.6291	.0000	1.	34.6291	34.6291	1.	48.
43	5.2832	.0000	1.	5.2832	5.2832	.	26.
57	3.1106	.0000	1.	3.1106	3.1106	.	19.
71	.8409	.0000	1.	.8409	.8409	.	10.
91	2.7815	.0000	1.	2.7815	2.7815	.	22.
105	2.0000	.0000	1.	2.0000	2.0000	.	12.
119	20.2406	.0000	1.	20.2406	20.2406	.	53.
139	66.1192	.0000	1.	66.1192	66.1192	1.	88.
153	1.3979	.0000	1.	1.3979	1.3979	.	11.

AVERAGE SERVER UTILIZATION						**TIME PERIODS OF SERVER**	
SERVER NO.	MEAN	STD.DEV.	NO. OF OBS.	MIN.	MAX.	LONGEST PERIOD IDLE	LONGEST PERIOD BUSY
198	.3400	.0000	1.	.3400	.3400	34.4483	22.0000
197	.3600	.0000	1.	.3600	.3600	34.4483	24.0000
196	.3600	.0000	1.	.3600	.3600	34.4483	24.0000
195	.3600	.0000	1.	.3600	.3600	34.4483	24.0000
194	1.0000	.0000	1.	1.0000	1.0000	.0000	100.0000
193	1.0000	.0000	1.	1.0000	1.0000	.0000	100.0000
192	1.0000	.0000	1.	1.0000	1.0000	.0000	100.0000
191	1.0000	.0000	1.	1.0000	1.0000	.0000	100.0000
190	.8800	.0000	1.	.8800	.8800	2.8583	31.0754
189	.8175	.0000	1.	.8175	.8175	6.8583	29.5807
188	.8461	.0000	1.	.8461	.8461	4.0000	29.6807
187	.8575	.0000	1.	.8575	.8575	6.8583	29.6807
186	.5867	.0000	1.	.5867	.5867	6.9238	14.7685
185	.6467	.0000	1.	.6467	.6467	9.4187	14.7685
184	.6667	.0000	1.	.6667	.6667	6.9238	16.0000
183	.6467	.0000	1.	.6467	.6467	6.9238	14.7685
182	.3400	.0000	1.	.3400	.3400	12.8092	6.0000
181	.4000	.0000	1.	.4000	.4000	10.8892	8.0000
180	.3400	.0000	1.	.3400	.3400	12.8892	8.0000
179	.3400	.0000	1.	.3400	.3400	12.8892	8.0000
178	.4343	.0000	1.	.4343	.4343	18.6127	14.0000
177	.4543	.0000	1.	.4543	.4543	16.6127	12.0000
176	.4343	.0000	1.	.4343	.4343	16.6127	14.0000
175	.4743	.0000	1.	.4743	.4743	15.6127	18.5917
174	.5078	.0000	1.	.5078	.5078	10.5849	14.0000
173	.5478	.0000	1.	.5478	.5478	14.0975	14.0000
172	.5000	.0000	1.	.5000	.5000	15.5717	10.0000
171	.5600	.0000	1.	.5600	.5600	10.5849	14.0000
170	.9400	.0000	1.	.9400	.9400	4.5799	78.7493
169	.9400	.0000	1.	.9400	.9400	4.5799	78.7493
168	.9521	.0000	1.	.9521	.9521	2.6806	78.0563
167	.9790	.0000	1.	.9790	.9790	1.4201	78.7493
166	1.0000	.0000	1.	1.0000	1.0000	.0000	100.0000
165	1.0000	.0000	1.	1.0000	1.0000	.0000	100.0000
164	1.0000	.0000	1.	1.0000	1.0000	.0000	100.0000
163	1.0000	.0000	1.	1.0000	1.0000	.0000	100.0000
162	.5098	.0000	1.	.5098	.5098	9.0920	8.0000
161	.4898	.0000	1.	.4898	.4898	10.0920	12.0000
160	.5498	.0000	1.	.5498	.5498	8.0920	8.0000
159	.5098	.0000	1.	.5098	.5098	8.0920	12.0000

HISTOGRAMS

NODE	LOWER LIMIT	CELL WIDTH	FREQUENCIES										
173	.00	1.00	0	0	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	1		
194	.00	1.00	0	0	0	0	0	6	9	11	15	15	14
			4	5	3	4	5	2	3	3	47		
192	.00	1.00	0	0	0	0	1	5	8	13	11	7	13
			4	6	2	2	2	3	1	0	5		
190	.00	1.00	0	0	0	0	1	1	4	8	4	4	2
			2	0	1	0	1	0	0	3	0		
186	.00	1.00	0	0	0	0	2	1	9	7	3	1	7
			2	2	2	3	1	3	1	1	19		
184	.00	1.00	0	0	0	0	0	6	2	13	7	12	9
			2	4	1	1	4	0	1	0	11		
182	.00	1.00	0	0	0	0	0	5	5	12	13	8	7
			4	2	1	1	0	0	1	0	12		
180	.00	1.00	0	0	0	0	0	0	5	0	7	6	6
			2	3	2	1	3	2	1	2	10		
176	.00	1.00	0	0	0	0	0	5	4	13	4	8	6
			4	1	0	1	3	1	0	0	20		
174	.00	1.00	0	0	0	0	0	5	3	11	7	8	7
			3	3	2	0	1	0	1	0	5		
172	.00	1.00	0	0	0	0	2	2	13	7	9	11	7
			1	4	2	2	3	2	0	2	2		
170	.00	1.00	0	0	0	0	0	0	1	1	10	0	9
			2	3	2	3	1	2	3	1	25		
168	.00	1.00	0	0	0	0	2	12	21	32	30	27	29
			10	11	6	6	8	5	4	3	52		
9	.00	1.00	0	0	0	1	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0		
23	.00	1.00	0	0	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	1		
43	.00	1.00	0	0	0	0	0	0	1	0	0	0	0
			0	0	0	0	0	0	0	0	0		
57	.00	1.00	0	0	0	0	1	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0		
71	.00	1.00	0	1	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0		
91	.00	1.00	0	0	0	1	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0		

Listing of GASP-IV Program for Circuit-Switched Communication Networks

APPENDIX F

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1  NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2  TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UOWN/IRT( 500,8),MLK(100),NLK(100),LST(100),TBB(100),
     1  TOB(100),PLACE(15,15),CARR(15),CDUR(15),PRI(15,5),ICA(15,15,5),
     2  ICB(15,15,5),ICP(15,15,5),ICD(15,15,5),ICC(15,15,5),
     3  IIRT(15,15,8),ITEMP(8),NODES,NLINK,ZENGT,STRST
      EQUIVALENCE(NSET(1),QSET(1))
      NCRDR=5
      NPRNT=6
      READ(NCRDR,1)NODES,NLINK,ZENGT,STRST
1     FORMAT(2I5,2F8.0)
      DO 11  IZM=1,NODES
      DO 11  IZN=1,NODES
11    PLACE(IZM,IZN)=0
      IZZ=1
C     INITIALIZE ROUTE FILE
      DO 2 I=1,500
      DO 2 J=1,8
2     IRT(I,J)=0
      DO 3 I=1,NODES
      DO 3 J=1,NODES
      DO 3 K=1,8
3     IIRT(I,J,K)=0
C     INPUT INFORMATION ABOUT SOURCES
      WRITE(NPRNT,4)
4     FORMAT(18X,20HECHO CHECK FOR NODES)
      DO 5 II=1,NODES
      READ(NCRDR,7)CARR(II),CDUR(II)
7     FORMAT(2F10.5)
      WRITE(NPRNT,8)II,CARR(II),CDUR(II)
8     FORMAT(///,10X,18HCALLS FROM SOURCE ,I2,//,15X,
     1  27HAVERAGE TIME BETWEEN CALLS ,F10.5,//,15X,
     2  25HAVERAGE DURATION OF CALL ,F10.5)
C     PRIORITY OF CALLS
      READ(NCRDR,9)(PRI(II,K),K=1,5)
9     FORMAT(5F5.3)
      WRITE(NPRNT,10)(PRI(II,K),K=1,5)

10    FORMAT(//,15X,35HPROBABILITY OF PRIORITY 1 CALLS IS ,F5.3,/,
     1            15X,35HPROBABILITY OF PRIORITY 2 CALLS IS ,F5.3,/,
     2            15X,35HPROBABILITY OF PRIORITY 3 CALLS IS ,F5.3,/,
     3            15X,35HPROBABILITY OF PRIORITY 4 CALLS IS ,F5.3,/,
     4            15X,35HPROBABILITY OF PRIORITY 5 CALLS IS ,F5.3)
C     DESTINATION INFORMATION
15    READ(NCRDR,12)JJ,PROB,NUM
      IF(JJ.LT.0)GO TO 5
      WRITE(NPRNT,13)JJ,PROB
12    FORMAT(I5,F5.3,I5)
13    FORMAT(///,18X,36HPROBABILITY OF A CALL GOING TO SINK ,I5,4H IS ,
     1  F5.3,/,24X,30HROUTES IN ORDER OF PREFERENCE )
      PLACE(II,JJ)=PROB
      DO 17  I=1,NUM
      READ(NCRDR,19)(ITEMP(J),J=1,8)
19    FORMAT(8I5)
      IE=2
24    IF(ITEMP(IE).EQ.0)GO TO 25
      IE=IE+1
      IF(IE.EQ.9)GO TO 25
      GO TO 24
25    IE=IE-1
      DO 26  J=1,IE
26    IRT(IZZ,J)=ITEMP(J)
      IIRT(II,JJ,I)=IZZ
      IZZ=IZZ+1
      GO TO  (31,32,33,34,35,36,37,38) IE
31    WRITE(NPRNT,39)ITEMP(1)
      GO TO  17
32    WRITE(NPRNT,39)(ITEMP(MZ),MZ=1,2)
      GO TO  17
33    WRITE(NPRNT,39)(ITEMP(MZ),MZ=1,3)
      GO TO  17
34    WRITE(NPRNT,39)(ITEMP(MZ),MZ=1,4)
      GO TO  17
```

```
35     WRITE(NPRNT,39)(ITEMP(MZ),MZ=1,5)
       GO TO 17
36     WRITE(NPRNT,39)(ITEMP(MZ),MZ=1,6)
       GO TO 17
37     WRITE(NPRNT,39)(ITEMP(MZ),MZ=1,7)
       GO TO 17
38     WRITE(NPRNT,39)(ITEMP(MZ),MZ=1,8)
17     CONTINUE
39     FORMAT(27X,8I7)
       GO TO 15
5      CONTINUE
C      INFORMATICN ABOUT LINKS
       WRITE(NPPNT,100)
100    FORMAT(///,15X,29HTRANSMISSION LINK INFORMATION,//,18X,4HLINK,
     1  7X,5HLINES,6X,12HTIME BETWEEN,7X,9HBREAKDOWN,/,41X,
     2  9HBREAKDOWN,10X,8HDURATION)
       DO 109 I=1,NLINK
       READ(NCRDR,102)MLK(I),TBB(I),TOB(I)
102    FORMAT(I5,F8.2,F8.3)
109    WRITE(NPRNT,101)I,MLK(I),TBB(I),TOB(I)
101    FORMAT(18X,I4,7X,I4,8X,F8.2,7X,F8.3)
       CALL GASP
       CALL EXIT
       END
```

```
      SUBROUTINE EVNTS(IX)
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1  NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2  TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCWN/IRT( 500,8),MLK(100),NLK(100),LST(100),TBB(100),
     1  TOB(100),PLACE(15,15),CARR(15),CDUR(15),PRI(15,5),ICA(15,15,5),
     2  ICB(15,15,5),ICP(15,15,5),ICD(15,15,5),ICC(15,15,5),
     3  IIRT(15,15,8),ITEMP(8),NODES,NLINK,ZENGT,STRST
      EQUIVALENCE(NSET(1),QSET(1))
      GO TO(101,102,103,104,105,106)IX
101   CALL GENCL
      RETURN
102   CALL ENDCL
      RETURN
103   CALL LNKDN
      RETURN
104   CALL LNKUP
      RETURN
105   CALL ITTST
      RETURN
106   CALL ENSIM
      RETURN
      END
```

```
      SUBROUTINE GENCL
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1  NCRDP,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2  TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCWN/IRT( 500,8),MLK(100),NLK(100),LST(100),TBB(100),
     1  TOB(100),PLACE(15,15),CARR(15),CDUR(15),PRI(15,5),ICA(15,15,5),
     2  ICB(15,15,5),ICP(15,15,5),ICU(15,15,5),ICC(15,15,5),
     3  IIRT(15,15,8),ITEMP(8),NODES,NLINK,ZENGT,STRST
      EQUIVALENCE(NSET(1),QSET(1))
C     SCHEDULE NEXT CALL
      II=ATRIB(3)
      ATRIB(1)=TNOW+EXPON(CARR(II),1)
      CALL FILEM(1)
      RND=DRAND(5)
      IP=0
100   IP=IP+1
      RND=RND-PRI(II,IP)
      IF(RND.GT.0)GO TO 100
      ATRIB(5)=IP
C     DETERMINE SINK
      RND=DRAND(5)
      IJ=0
110   IJ=IJ+1
      RND=RND-PLACE(II,IJ)
      IF(RND.GT.0)GO TO 110
      ATRIB(4)=IJ
      ICA(II,IJ,IP)=ICA(II,IJ,IP)+1
C     SEE IF ROUTE IS AVAILABLE
      IZ=0
505   IZ=IZ+1
      IF(IZ.GT.8)GO TO 1500
      IF(IIRT(II,IJ,IZ).EQ.0)GO TO 1500
      IR=IIRT(II,IJ,IZ)
      IQ=0
600   IQ=IQ+1
      IF(IQ.GT.8)GO TO 1000
      IL=IRT(IR,IQ)
      IF(IL.LE.0)GO TO 1000
      IF(LST(IL).GT.0.5)GO TO 505
      IF(NLK(IL).EQ.MLK(IL))GO TO 505
      GO TO 600
C     GOOD ROUTE FOUND. INCREMENT LINKS.
1000  IA=0
69    IA=IA+1
      IF(IA.GT.8)GO TO 300
      IAA=IRT(IR,IA)
      IF(IAA.EQ.0)GO TO 300
      NLK(IAA)=NLK(IAA)+1
      GO TO 69
C     SCHEDULE END OF CALL
300   ATRIB(1)=TNOW+EXPON(CDUR(II),1)
      ATRIB(2)=2.
      ATRIB(3)=II
      ATRIB(4)=IJ
      ATRIB(5)=IP
      ATRIB(6)=IR
      CALL FILEM(1)
      RETURN
C     DETERMINE IF JOB CAN BE PREEMPTED
1500  IF(IP.EQ.1)GO TO 1400
C     SEARCH FILE
      NEXT=MFE(1)
550   CALL COPY(NEXT)
      NNEXT=NEXT+NNAPO
      NNEXT=NSET(NNEXT)
      IF(ATRIB(2).NE.2.)GO TO 900
      JI=ATRIB(3)
      JJ=ATRIB(4)
      JP=ATRIB(5)
      JR=ATRIB(6)
      IF(JR.NE.IR)GO TO 900
      IF(II.NE.JI)GO TO 900
      IF(IJ.NE.JJ)GO TO 900
      IF(IP.GT.JP)GO TO 950
900   IF(NNEXT.EQ.0)GO TO 1400
```

```
      NEXT=NNEXT
      GO TO 550
C     REMOVE ENTRY
950   CALL RMOVE(NEXT,1)
      ICP(II,IJ,JP)=ICP(II,IJ,JP)+1
      ATRIB(5)=IP
      ATRIB(1)=TNOW+EXPON(CARR(II),1)
      CALL FILEM(1)
      RETURN
1400  ICB(II,IJ,IP)=ICB(II,IJ,IP)+1
      RETURN
      END
```

```
      SUBROUTINE ENDCL
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1  NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2  TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCWN/IRT( 500,8),MLK(100),NLK(100),LST(100),TBB(100),
     1  TOB(100),PLACE(15,15),CARR(15),CDUR(15),PRI(15,5),ICA(15,15,5),
     2  ICB(15,15,5),ICP(15,15,5),ICD(15,15,5),ICC(15,15,5),
     3  IIRT(15,15,8),ITEMP(8),NODES,NLINK,ZENGT,STRST
      EQUIVALENCE(NSET(1),QSET(1))
C     RECORD COMPLETED CALL
      II=ATRIB(3)
      IJ=ATRIB(4)
      IP=ATPIB(5)
      IR=ATRIB(6)
      ICC(II,IJ,IP)=ICC(II,IJ,IP)+1
C     RELEASE LINKS
      IX=1
7     IF(IX.GT.8)GO TO 100
      IF(IRT(IR,IX).EQ.0)GO TO 100
      IZ=IRT(IR,IX)
      NLK(IZ)=NLK(IZ)-1
      IX=IX+1
      GO TO 7
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LNKDN
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1  NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2  TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCWN/IRT( 500,8),MLK(100),NLK(100),LST(100),TBB(100),
     1  TOB(100),PLACE(15,15),CARR(15),CDUR(15),PRI(15,5),ICA(15,15,5),
     2  ICB(15,15,5),ICP(15,15,5),ICD(15,15,5),ICC(15,15,5),
     3  IIRT(15,15,8),ITEMP(8),NODES,NLINK,ZENGT,STRST
      EQUIVALENCE(NSET(1),QSET(1))
C     SCHEDULE LINK DOWN
      JJ=ATRIB(3)
      LST(JJ)=1
C     SCHEDULE END OF BREAKDOWN
      ATRIB(1)=TNOW+EXPON(TOB(JJ),3)
      ATRIB(2)=4.
      CALL FILEM(1)
C     DETERMINE IF CALL WILL BE LOST. STEP THROUGH FILE 1.
      NEXT=MFE(1)
50    CALL COPY(NEXT)
      NNEXT=NEXT+NNAPO
      NNEXT=NSET(NNEXT)
      IF(ATRIB(2).NE.2.)GO TO 100
      II=ATRIB(3)
      IJ=ATRIB(4)
      IP=ATRIB(5)
      IR=ATRIB(6)
C     CHECK  ROUTE TO SEE IF CALL IS LOST
      IX=1
20    IF(IX.GT.8)GO TO 100
      IF(IRT(IR,IX).EQ.0)GO TO 100
      IF(IRT(IR,IX).EQ.JJ)GO TO 200
      IX=IX+1
      GO TO 20
C     LINK FOUND. DECREASE OTHER LINKS.
200   IX=1
30    IF(IX.GT.8)GO TO 201
      IZ=IRT(IR,IX)
      IF(IZ.EQ.0)GO TO 201
      NLK(IZ)=NLK(IZ)-1
      IX=IX+1
      GO TO 30
C     REMOVE CALL AND RECORD DROPPED CALL
201   ICD(II,IJ,IP)=ICD(II,IJ,IP)+1
      CALL RMOVE(NEXT,1)
C     FIND NEXT ENTRY
100   IF(NNEXT.EQ.0)GO TO 400
      NEXT=NNEXT
      GO TO 50
400   NLK(JJ)=0
      RETURN
      END
```

```
      SUBROUTINE LNKUP
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1  NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2  TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCWN/IRT( 500,8),MLK(100),NLK(100),LST(100),TBB(100),
     1  TOB(100),PLACE(15,15),CARR(15),COUR(15),PRI(15,5),ICA(15,15,5),
     2  ICB(15,15,5),ICP(15,15,5),ICD(15,15,5),ICC(15,15,5),
     3  IIRT(15,15,8),ITEMP(8),NODES,NLINK,ZENGT,STRST
      EQUIVALENCE(NSET(1),QSET(1))
C     SCHEDULE NEXT BREAKDOWN
      JJ=ATRIB(3)
      ATRIB(1)=TNOW+FXPON(TBB(JJ),1)
      ATRIB(2)=3.0
      CALL FILEM(1)
C     CHANGE STATUS OF LINK
      LST(JJ)=0
      RETURN
      END
```

```
      SUBROUTINE ITTST
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1  NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2  TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCWN/IRT( 500,8),MLK(100),NLK(100),LST(100),TBB(100),
     1  TOB(100),PLACE(15,15),CARR(15),COUR(15),PRI(15,5),ICA(15,15,5),
     2  ICB(15,15,5),ICP(15,15,5),ICD(15,15,5),ICC(15,15,5),
     3  IIRT(15,15,8),ITEMP(8),NODES,NLINK,ZENGT,STRST
      EQUIVALENCE(NSET(1),QSET(1))
C     INITIALIZE ROUTE STATISTICS
      DO 1 I=1,NODES
      DO 1 J=1,NODES
      DO 1 K=1,5
      ICA(I,J,K)=ICA(I,J,K)-ICC(I,J,K)-ICB(I,J,K)-ICD(I,J,K)-ICP(I,J,K)
      ICB(I,J,K)=0
      ICP(I,J,K)=0
      ICD(I,J,K)=0
    1 ICC(I,J,K)=0
      RETURN
      END
```

```
      SUBROUTINE ENSIM
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1  NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2  TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UCWN/IRT( 500,8),MLK(100),NLK(100),LST(100),TBB(100),
     1  TOB(100),PLACE(15,15),CARR(15),CDUR(15),PRI(15,5),ICA(15,15,5),
     2  ICB(15,15,5),ICP(15,15,5),ICD(15,15,5),ICC(15,15,5),
     3  IIRT(15,15,8),ITEMP(8),NODES,NLINK,ZENGT,STRST
      EQUIVALENCE(NSET(1),QSET(1))
1     FORMAT(//,30X,39HOUTPUT OF SWITCHING CIRCUIT PERFORMANCE,/)
2     FORMAT(10X,6HSOURCE,6X,4HSINK,4X,8HPRIORITY,10X,6HSTATUS,10X,
     1  3HOPS,9X,10HPROPORTION)
3     FORMAT(/,10X,I4,7X,I4,8X,I3,5X,15HCALLS ATTEMPTED,9X,I6,5X,F6.4)
4     FORMAT(41X,15HCALLS COMPLETED,9X,I6,5X,F6.4)
5     FORMAT(41X,13HCALLS BLOCKED,11X,I6,5X,F6.4)
6     FORMAT(41X,13HCALLS DROPPED,11X,I6,5X,F6.4)
7     FORMAT(41X,15HCALLS PREEMPTED,9X,I6,5X,F6.4)
8     FORMAT(41X,17HCALLS IN PROGRESS,7X,I6,5X,F6.4)
      DO 9 II=1,NODES
      DO 9 IJ=1,NODES
      DO 9 IP=1,5
      IF(II.EQ.IJ)GO TO 9
      ISUM=ICC(II,IJ,IP)+ICB(II,IJ,IP)+ICD(II,IJ,IP)+ICP(II,IJ,IP)
      IREM=ICA(II,IJ,IP)-ISUM
      PZ=FLOAT(ICA(II,IJ,IP))
      PA=1.00
      PC=FLOAT(ICC(II,IJ,IP))/PZ
      PB=FLOAT(ICB(II,IJ,IP))/PZ
      PD=FLOAT(ICD(II,IJ,IP))/PZ
      PP=FLOAT(ICP(II,IJ,IP))/PZ
      PR=FLOAT(IREM)/PZ
      WRITE(NPRNT,1)
      MSTOP=-1
      WRITE(NPRNT,2)
      WRITE(NPRNT,3)II,IJ,IP,ICA(II,IJ,IP),PA
      WRITE(NPRNT,4)ICC(II,IJ,IP),PC
      WRITE(NPRNT,5)ICB(II,IJ,IP),PB
      WRITE(NPRNT,6)ICD(II,IJ,IP),PD
      WRITE(NPRNT,7)ICP(II,IJ,IP),PP
      WRITE(NPRNT,8)IREM,PR
9     CONTINUE
      RETURN
      ENJ
```

```
      SUBROUTINE INTLC
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      COMMON/GCOM1/ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1  NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2  TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON/UOWN/IRT( 500,8),MLK(100),NLK(100),LST(100),TBB(100),
     1  TOB(100),PLACE(15,15),CARR(15),CDUR(15),PRI(15,5),ICA(15,15,5),
     2  ICB(15,15,5),ICP(15,15,5),ICD(15,15,5),ICC(15,15,5),
     3  IIRT(15,15,8),ITEMP(8),NODES,NLINK,ZENGT,STRST
      EQUIVALENCE(NSET(1),QSET(1))
      ATRIB(4)=0.
      ATRIB(5)=0.
      ATRIB(6)=0.
C     INITIALIZE LINK INFORMATION AND BREAKDOWNS
      DO 3 I=1,NLINK
      NLK(I)=0
      LST(I)=0
      ATRIB(1)=EXPON(TBB(1),1)
      ATRIB(2)=3.0
      ATRIB(3)=I
3     CALL FILEM(1)
C     INITIALIZE DEMAND FOR CALLS
      DO 2 J=1,NODES
      ATRIB(1)=EXPON(CARR(J),2)
      ATRIB(2)=1.
      ATRIB(3)=J
2     CALL FILEM(1)
C     INITIALIZE STATISTICS VARIABLES
      DO 1 I=1,NODES
      DO 1 J=1,NODES
      DO 1 K=1,5
      ICA(I,J,K)=0
      ICB(I,J,K)=0
      ICP(I,J,K)=0
      ICD(I,J,K)=0
1     ICC(I,J,K)=0
      ATRIB(1)=STRST
      ATRIB(2)=5.
      ATRIB(3)=0.
      CALL FILEM(1)
C     SCHEDULE END OF SIMULATION
      ATRIB(1)=STRST+ZENGT
      ATRIB(2)=6.
      CALL FILEM(1)
      RETURN
      END
```

Sample Output from GASP-IV Program

APPENDIX G

```
CALLS FROM SOURCE  1

     AVERAGE TIME BETWEEN CALLS      .25000

     AVERAGE DURATION OF CALL      .40000


     PROBABILITY OF PRIORITY 1 CALLS IS  .750
     PROBABILITY OF PRIORITY 2 CALLS IS  .050
     PROBABILITY OF PRIORITY 3 CALLS IS  .100
     PROBABILITY OF PRIORITY 4 CALLS IS  .050
     PROBABILITY OF PRIORITY 5 CALLS IS  .050


        PROBABILITY OF A CALL GOING TO SINK      2 IS  .400
              ROUTES IN ORDER OF PREFERENCE
                       1
                       4      7
                       9      3      2


        PROBABILITY OF A CALL GOING TO SINK      3 IS  .400
              ROUTES IN ORDER OF PREFERENCE
                       1      2
                       4      5      3
                       8


        PROBABILITY OF A CALL GOING TO SINK      5 IS  .200
              ROUTES IN ORDER OF PREFERENCE
                       4
                       1      2      6


CALLS FROM SOURCE  2

     AVERAGE TIME BETWEEN CALLS      .50000

     AVERAGE DURATION OF CALL      .50000


     PROBABILITY OF PRIORITY 1 CALLS IS  .900
     PROBABILITY OF PRIORITY 2 CALLS IS  .050
     PROBABILITY OF PRIORITY 3 CALLS IS  .050
     PROBABILITY OF PRIORITY 4 CALLS IS -.000
     PROBABILITY OF PRIORITY 5 CALLS IS -.000


        PROBABILITY OF A CALL GOING TO SINK      1 IS  .200
              ROUTES IN ORDER OF PREFERENCE
                       1
                       4      7
                       9      3      2


        PROBABILITY OF A CALL GOING TO SINK      3 IS  .400
              ROUTES IN ORDER OF PREFERENCE
                       2
                       7      6
```

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        PROBABILITY OF A CALL GOING TO SINK      4 IS  .300
              ROUTES IN ORDER OF PREFERENCE
                        2       3
                        7       5
                        1       8       3
                        7       4       9


        PROBABILITY OF A CALL GOING TO SINK      5 IS  .100
              ROUTES IN ORDER OF PREFERENCE
                        7


CALLS FROM SOURCE  3

     AVERAGE TIME BETWEEN CALLS      .10000

     AVERAGE DURATION OF CALL      .30000

     PROBABILITY OF PRIORITY 1 CALLS IS  .500
     PROBABILITY OF PRIORITY 2 CALLS IS  .200
     PROBABILITY OF PRIORITY 3 CALLS IS  .100
     PROBABILITY OF PRIORITY 4 CALLS IS  .100
     PROBABILITY OF PRIORITY 5 CALLS IS  .100


        PROBABILITY OF A CALL GOING TO SINK      1 IS  .100
              ROUTES IN ORDER OF PREFERENCE
                        8
                        6       4


        PROBABILITY OF A CALL GOING TO SINK      2 IS  .300
              ROUTES IN ORDER OF PREFERENCE
                        2
                        6       4
                        3       5       4
                        6       7       1


        PROBABILITY OF A CALL GOING TO SINK      4 IS  .300
              ROUTES IN ORDER OF PREFERENCE
                        3
                        2       1       9


        PROBABILITY OF A CALL GOING TO SINK      5 IS  .300
              ROUTES IN ORDER OF PREFERENCE
                        8       9
                        6


CALLS FROM SOURCE  4

     AVERAGE TIME BETWEEN CALLS      .20000

     AVERAGE DURATION OF CALL      .20000
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PROBABILITY OF PRIORITY 1 CALLS IS  .600
PROBABILITY OF PRIORITY 2 CALLS IS  .300
PROBABILITY OF PRIORITY 3 CALLS IS  .050
PROBABILITY OF PRIORITY 4 CALLS IS  .030
PROBABILITY OF PRIORITY 5 CALLS IS  .020


   PROBABILITY OF A CALL GOING TO SINK     1 IS  .300
         ROUTES IN ORDER OF PREFERENCE
                  9
                  3      6      4
                  5      7


   PROBABILITY OF A CALL GOING TO SINK     2 IS  .300
         ROUTES IN ORDER OF PREFERENCE
                  9      1
                  3      2
                  5      7
                  5      6      2


   PROBABILITY OF A CALL GOING TO SINK     3 IS  .200
         ROUTES IN ORDER OF PREFERENCE
                  9      8
                  9      1      2
                  5      4      8
                  5      4      1      2
                  5      6
                  5      7      2
                  3


   PROBABILITY OF A CALL GOING TO SINK     5 IS  .200
         ROUTES IN ORDER OF PREFERENCE
                  5


CALLS FROM SOURCE  5

     AVERAGE TIME BETWEEN CALLS      .50000

     AVERAGE DURATION OF CALL      .60000

     PROBABILITY OF PRIORITY 1 CALLS IS  .400
     PROBABILITY OF PRIORITY 2 CALLS IS  .300
     PROBABILITY OF PRIORITY 3 CALLS IS  .100
     PROBABILITY OF PRIORITY 4 CALLS IS  .150
     PROBABILITY OF PRIORITY 5 CALLS IS  .050


   PROBABILITY OF A CALL GOING TO SINK     1 IS  .400
         ROUTES IN ORDER OF PREFERENCE
                  4
                  7      1
                  5      3      2      1
```

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PROBABILITY OF A CALL GOING TO SINK      2 IS  .400
      ROUTES IN ORDER OF PREFERENCE
               5      9      1
               7
               6      2


PROBABILITY OF A CALL GOING TO SINK      3 IS  .100
      ROUTES IN ORDER OF PREFERENCE
               6


PROBABILITY OF A CALL GOING TO SINK      4 IS  .100
      ROUTES IN ORDER OF PREFERENCE
               4      9
               4      8      3
               5
               6      3
               7      2      8      9
```

TRANSMISSION LINK INFORMATION

LINK	LINES	TIME BETWEEN BREAKDOWN	BREAKDOWN DURATION
1	5	40.00	2.000
2	6	60.00	.900
3	7	60.00	.500
4	4	90.00	1.500
5	3	100.00	1.000
6	6	40.00	.500
7	7	30.00	1.000
8	10	200.00	4.000
9	4	50.00	.500

OUTPUT OF SWITCHING CIRCUIT PERFORMANCE

SOURCE	SINK	PRIORITY	STATUS	OBS	PROPORTION
3	5	1	CALLS ATTEMPTED	150	1.0000
			CALLS COMPLETED	106	.7067
			CALLS BLOCKED	24	.1600
			CALLS DROPPED	1	.0067
			CALLS PREEMPTED	15	.1000
			CALLS IN PROGRESS	4	.0267

OUTPUT OF SWITCHING CIRCUIT PERFORMANCE

SOURCE	SINK	PRIORITY	STATUS	OBS	PROPORTION
3	5	2	CALLS ATTEMPTED	66	1.0000
			CALLS COMPLETED	58	.8788
			CALLS BLOCKED	4	.0606
			CALLS DROPPED	2	.0303
			CALLS PREEMPTED	2	.0303
			CALLS IN PROGRESS	0	.0000

OUTPUT OF SWITCHING CIRCUIT PERFORMANCE

SOURCE	SINK	PRIORITY	STATUS	OBS	PROPORTION
3	5	3	CALLS ATTEMPTED	30	1.0000
			CALLS COMPLETED	28	.9333
			CALLS BLOCKED	1	.0333
			CALLS DROPPED	1	.0333
			CALLS PREEMPTED	0	.0000
			CALLS IN PROGRESS	0	.0000

OUTPUT OF SWITCHING CIRCUIT PERFORMANCE

SOURCE	SINK	PRIORITY	STATUS	OBS	PROPORTION
3	5	4	CALLS ATTEMPTED	27	1.0000
			CALLS COMPLETED	26	.9630
			CALLS BLOCKED	0	.0000
			CALLS DROPPED	0	.0000
			CALLS PREEMPTED	0	.0000
			CALLS IN PROGRESS	1	.0370

OUTPUT OF SWITCHING CIRCUIT PERFORMANCE

SOURCE	SINK	PRIORITY	STATUS	OBS	PROPORTION
3	5	5	CALLS ATTEMPTED	24	1.0000
			CALLS COMPLETED	23	.9583
			CALLS BLOCKED	0	.0000
			CALLS DROPPED	1	.0417
			CALLS PREEMPTED	0	.0000
			CALLS IN PROGRESS	0	.0000